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STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISION OF PLANT PATHOLOGY

**The Wind Dissemination of the
Spores of Bunt or Stinking
Smut of Wheat**

By

F. D. HEALD and D. C. GEORGE

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THE WIND DISSEMINATION OF THE SPORES OF BUNT OR STINKING SMUT OF WHEAT

By F. D. Heald and D. C. George*

INTRODUCTION

During recent years the increased prevalence of stinking smut in the wheat fields of the Indand Empire has furnished one of the most important agricultural problems. This disease has been a growing menace to wheat production, notwithstanding the fact that seed disinfection has been very generally practiced. No satisfactory explanation had ever been offered for this rather unique condition previous to the investigations upon which this report is based. The recognition and establishment of the cause of the wide-spread occurrence of stinking smut is fundamental to the development of rational and effective methods of control.

The wide-spread occurrence of a fungous disease points to an effective dissemination, either natural or artificial. Fungous troubles may be seed-borne, or they may be disseminated by wind, water, insects, birds or other animals or by the commercial or agricultural practices of man. Since early times the stinking smut of wheat has been recognized as one of the most important seed-borne diseases, and seed treatment with fungicides has generally been effective in its control. The failure to secure the desired relief by seed treatment naturally suggests some other general method of dissemination aside from the use of infected seed. Work was begun on this phase of the smut problem in the summer of 1915 and has been continued up to the present time. Before presenting this work, a brief statement will be made concerning the general methods of dissemination of the smut fungi of cereals and the time when infection takes place.

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THE DISSEMINATION OF SMUT FUNGI OF CEREALS

The various smut fungi of cereals show a pronounced diversity in the methods of spore dissemination and in the time when infection takes place. Three general types may be recognized and a brief discussion of these will be presented in order that a clear view may be obtained of the particular species which forms the subject of this study. According to time of infection, the three groups are as follows:

1. Species producing a blossom infection.
2. Species infecting growing plants or those approaching maturity.
3. Species infecting only young seedlings.

In the first group the smut spores reach maturity in infected heads at a time when the flowers of the normal heads are in the blossom stage. The loose powdery mass of smut spores is dissipated by the wind, and the spores carried to the projecting feathery stigmas of the healthy plants. There is a direct germination of the spores with the infection of the young developing ovaries. This intraseminal infection causes no outward indication of the presence of an internal mycelium and the infected grains assume normal form and size. Such infected grains, when planted, may produce diseased progeny. The spread of the disease is due, first, to wind-borne spores during the blossoming period, and second, to the use of infected seed. This behavior is well illustrated by the loose smut of wheat (*Ustilago tritici*) and the naked smut of barley (*Ustilago nuda*.)

The second type is illustrated by the common smut of corn. Young plants or those approaching maturity are infected by wind-borne secondary spores or sporidia, which have resulted from the germination of the smut spores in the surface layers of the soil. The infections in this case are localized and not systemic, the mycelium penetrating the host only in the tissues adjacent to the tumors. Although spores of this species may be spread in other ways, the wind is the principal agent in the work of dissemination.

In the third type, which includes the larger number of our cereal smuts, the infection can take place only during the young or seedling stage of the host. The first essential for infection is the presence of smut spores in close proximity to the germinating seeds. These spores may be lodged upon the seeds and carried with them into the soil, or they may already be in the soil at the time of seeding. The source of the spores in the latter case must be either from a previous smutty crop on the ground (residual) or from adjacent or distant infected fields (wind-borne). Notable illustrations of this third type are loose smut of oats (*Ustilago avenae*) covered smut of barley (*Ustilago hordei*) and bunt or stinking smut of wheat (*Tilletia tritici* and *Tilletia foetans*). In the latter species all of the above sources of infection may occur, but our investigations have shown that wind-borne spores are very prevalent in Eastern Washington and adjacent territory. This is a phase of the dissemination of bunt which will receive special consideration in the following pages.

STUDIES OF STINKING SMUT IN WASHINGTON

A study of the work published by the Washington Experiment Station shows that first attention was given to seed treatment the same as in other wheat regions of the world. By 1911 the increased prevalence of smut in the Inland Empire due to fall seeding suggested the possibility of soil infection and the part of wind-disseminated spores in this increase was first suggested by Richardson in a thesis written in 1911 and further elaborated by Heald and Woolman in 1915 and 1916. The following publications by the Washington Station are given in chronological order and the brief summaries show the changing conditions and the development of our knowledge on the life history, prevalence, and control of bunt:

Piper, Chas. V.

1893. Common fungous diseases and methods of prevention. Bul. Wash. Agr. Exp. Sta. 8:131-144. 1894.

Description of stinking smut incorrectly referred to as *Tilletia foetans* Berk. & Curt.; recommends copper sulphate and hot water treatment, p. 135-136.

Beattie, R. Kent.

1902. The formalin treatment for wheat and oat smut. Bul. Wash. Agr. Exp. Sta. 54:1-8.
Considers loss, variation in susceptibility of varieties, description of smut, copper sulphate and hot water treatments.

Beattie, R. Kent.

1902. (?) The formalin treatment for wheat smut. Press Bulletin Wash. Agr. Exp. Sta. (unnumbered) 4 pages.
Considers nature of smut, losses, ineffectiveness of bluestone treatment, and recommends the formalin treatment.

Lawrence, W. H.

1907. Some important plant diseases of Washington. Bul. Wash. Agr. Exp. Sta. 83:1-56. 1907.
Stinking smut (*Tilletia tritici*) described and the formaldehyde treatment recommended, p. 43-45.

Humphrey, H. B.

- ? The preventing of the stinking smut of wheat. Press Bulletin (unnumbered) Wash. Agr. Exp. Sta.

Anonymous.

1911. The anti-smut campaign. Press Bulletin Wash. Agr. Exp. Sta. No. 1.
Notes loss, increased prevalence due to fall seeding, possibility of soil infection and recommends copper sulphate or formaldehyde treatment.

Richardson, A. M.

1911. A comparative study of the methods of control of the stinking smut of wheat. Thesis (unpublished) on file in Library, State College of Washington.
Historical statement, life history of the fungus, partially smutted kernels, wind dissemination, treatments: hot water, copper sulphate and formaldehyde, are the principal topics discussed. Ineffectiveness of the two methods generally employed, blue stone and formaldehyde, reported by practical farmers. Tests of formaldehyde or copper sulphate and the two combined.

Humphrey, H. B.

1912. The preventing of the stinking smut of wheat. Popular Bul. Wash. Agr. Exp. Sta. 48:1-3.
Considers copper sulphate and formalin treatment, and points to soil infection as explanation of certain cases of ineffective results; also records failure of fungicides to penetrate smut balls.

Anonymous.

1912. Treating seed wheat for smut. Newspaper Bulletin Wash. Agr. Exp. Sta. No. 51.
Recommends either the formalin or bluestone seed treatment; emphasizes the importance of removing unbroken smut balls from the seed grain.

Woolman, H. M.

1914. Stinking smut of wheat. Popular Bul. Wash. Agr. Exp. Sta. 73, 8 pages.
Considers life history, breeding for resistant varieties, differences in susceptibility of varieties, time of application and strength of copper sulphate or formaldehyde in seed treatment, effect of threshing injury on germination of treated grain, persistence of spores in soil and effect of time of planting on the amount of smut.

Anonymous.

1914. Smut. Press Bulletin Wash. Agr. Exp. Sta. No. 113.
Refers only to Popular Bulletin 73.

Cardiff, I. D., et al.

1914. Report on fires occurring in threshing separators in East Washington during the summer of 1914. Bul. Wash. Agr. Exp. Sta. 117:1-22.
Demonstrates that smut dust is one of the causes of explosions in threshing separators and recommends methods of prevention and control.

Anonymous.

1915. Bunt or stinking smut of wheat. Newspaper Bulletin Wash. Agr. Exp. Sta. No. 160.
A summary of results reported later in Bulletin 126.

Heald, F. D., and Woolman, H. M.

1915. Bunt or stinking smut of wheat. Bul. Wash. Agr. Exp. Sta. 126:1-24.
Considers life history of smut fungus, effect on the host, infection from smutty seed, infection from spores in the soil, residual or wind borne, control by crop rotation, clean seed, treatment with fungicides, cultural practices and breeding and selection of varieties.

Heald, F. D.

1916. Some new facts concerning wheat smut. Proc. Wash. State Grain Growers, Shippers and Millers Association, 1916:38-45.
Emphasizes the occurrence of partially smutted grains and gives further evidence of a general and extensive wind dissemination of the spores.

Woolman, H. M.

1916. The prevention of wheat smut. Proc. Wash. State Grain Growers, Shippers and Millers Association, 1916:45-49.
Emphasizes the importance of using clean seed and using one of the standard seed treatments; gives methods of combatting soil infection from previous crops or from wind-blown spores.

Anonymous.

1916. Smut. Newspaper Bulletin Wash. Agr. Exp. Sta. No. 191. Emphasizes the soil infection by wind-blown spores and recommends either seeding before threshing time or late seeding or the abandonment of summer fallow wherever possible.

POSSIBILITIES OF WIND DISSEMINATION OF STINKING SMUT

The possibilities of a wind dissemination of bunt or stinking smut have been mentioned by a number of investigators. The first to be considered is the possibility of the production of wind-borne sporidia or secondary spores. This is not an unknown method of dissemination in cereal smuts, as may be noted from the following quotation from Brefeld:* "Some of these bud conidia are able to continue their budding in the air also and to form conidia there, which are disseminated through the air; as, for example, the bud conidia of the maize smut."

It has been observed that when spores of stinking smut are abundant in a soil, they may produce promycelia which come to the top of the moist soil and produce fascicles of sporidia in such profusion as to cause a grayish growth visible to the naked eye. This is apparently the condition which Brefeld had in mind when he mentioned the possibility of diffusible air conidia in bunt, or *Tilletia* species. If such conidia are borne away by wind or air currents, we have no evidence at present that they play a part in the general spread of stinking smut. Von Tubeuf,† who has experimented extensively with bunt in Europe, states that there is no spread of this disease from one plot to another and therefore concludes that there is no dissemination by aerial conidia.

There is little possibility of any wind dissemination of spores directly from the smutted heads as occurs in the case of loose

*Brefeld, O. Investigations in the general field of mycology. Part XIII, p. 7. English translation by Frances Dorance.

†Von Tubeuf, K. F. Arb. aus der Biol. Abteilung f. Land-u. Forstwirtschaft am Kaiserlichen Gesundheitsamt, 2:179-349. 1901.

smut. The smutted berries are wholly or partially concealed by the glumes and the smut mass covered by an enclosing membrane. Occasionally there may be a mechanical rupture of the enclosing membrane or the depredations of insects may result in the exposure of the smut spores, but there is no evidence that the agitation of these heads by the wind causes any appreciable liberation of the spores. Previous to harvest time there has been little or no opportunity for the dissemination of the smut spores. The first real opportunity offered for the setting free of the smut spores is in the threshing operations. It has long been a matter of general observation that many of the smut berries are broken in threshing and the spores dissipated. The extent to which this occurs depends on numerous factors, such as variety, maturity of crop at harvest, climatic conditions and speed of the threshing machine. The yield from very smutty fields sometimes shows a relatively small number of unbroken smut berries, the greater number having been broken. Part of the spores from the broken smut kernels adhere to the surfaces of sound grains, or are lodged in the sutures and brushes, but many must be carried out through the straw carrier, or stacker. The ultimate fate of the latter is of the utmost importance and indicates the possibility of wide-spread dissemination of these spores by the wind.

SUGGESTIVE EVIDENCE OF THE WIND DISSEMINATION OF SMUT

Various observations and experiences have given strong suggestive evidence of the wind dissemination of the spores of bunt. The following are the principal suggestive features that were brought to our attention and led up to the work which established the wide-spread prevalence of wind-disseminated spores.

1. The visible clouds of smut dust which issue from the threshing machines whenever the run is from a smutty field. Even with the use of ordinary separators, the innumerable number of settings must certainly set free into the air countless billions of spores, while the use of the combine serves as

an even more effective distributor. It must at once be evident that the spores in these visible clouds, being very minute, do not settle to the ground at once, and that their final place of deposit depends largely on the velocity of the wind. Any reflection on this matter would certainly lead to the conclusion that many of the smut spores set free from each threshing operation might be carried away for miles and thus scattered over the fields.

2. The presence of smut spores on vegetation distant from any threshing operation. This was first brought to our attention when making microscopic examinations of scab lesions on the leaves of apple trees from the College orchard. Wind dissemination of the spores was the evident explanation for their presence in such a location and this accidental discovery led to the systematic examination of foliage from various localities as will be discussed later.

3. Smutty wheat from clean seed on new land. This has been referred to in a previous publication* and will not be repeated in full. In some 1914 plantings on new soil using hand-threshed grain from smut-free heads, the percentages of smutted plants varied from a fraction of one per cent to sixty per cent. No other possible explanation for these results could be found except that the ground had been seeded with wind-blown spores.

4. The ineffectiveness of ordinary seed treatment for fall seeding. Two explanations for the failure to secure satisfactory results by seed disinfection had been given: first, the failure to remove the unbroken smut balls, either before or during the process of the treatment; second, soil infection due to a previous smutty crop on the same land. When, however, both of these possibilities were eliminated, carefully treated wheat frequently showed varying percentages of smut in the crop.

The apparent ineffectiveness of seed disinfection was the principal factor which led to the recommendation of the open

*Heald, F. D., and Woolman, H. M. Bunt or stinking smut of wheat. Bul. Wash. Agr. Exp. Sta. 126:1-24. 1915.

tank method of seed treatment, rather than to any actual demonstration of the part which the unbroken smut balls played in these results.

Spring plantings have shown little or no smut when the seed has been carefully treated, but fall plantings on summer fallow have very frequently shown high percentages of smut. The following records taken from information collected by Dr. H. B. Humphrey and H. M. Woolman, were typical of the farm conditions in the vicinity of Pullman:

TABLE I.

Percentages of Smut on Winter Wheat with Careful Seed Treatment (Blustone)

Tract	Year	On Sum. Fal.	Variety	Percentage of Smut
146	1912	1911	Forty Fold	10-18 North Slope
144	1912	1911	Red Russian	20-25 North Slope
142	1912	1911	Club ?	30
136	1912	1911	Hybrid 108	21-24 South Slope
133	1912	1911	Hybrid 128	15-20 North Slope
129	1914	1913	Red Russian	15-20
131	1914	1913	Hybrid 143	22 North Slope

POSITIVE EVIDENCE OF WIND DISSEMINATION OF STINKING SMUT

Foliage Collections. The discovery of the spores of bunt on the leaves of apple (already mentioned) led to a more systematic search for these spores on the foliage of various plants. During the fall of 1915, leaf collections were made from various localities from the following: prairie sunflowers (*Balsamorhiza*), apple, maple, catalpa, box elder, spiraea, and snowberry (*Symphoricarpos*). Each lot (usually 25 leaves) was put at once into a clean paper sack and brought to the laboratory. With a clean test tube brush the surfaces of each leaf were scrubbed in a small amount of distilled water in a damp chamber. The operation of scrubbing was carried out in the laboratory inoculation chamber, thus allowing no spores to enter from the outside. To the washings was then added a sufficient amount of formalin to prevent the germination of the spores, and the entire amount placed in clean flasks or

bottles properly labeled and numbered. Counts determining the approximate number of spores present, were made at a later date.

The quantitative determination of the number of bunt spores found present on each lot was determined by the following method. The flasks containing the washings were thoroughly shaken in order to get into suspension all the spores present. With a 1 c.c. pipette a drop was removed to a clean slide and covered with a 22mm. slip, the edges of which had been smeared with vaseline to prevent the evaporation of the water during the count. By use of the mechanical stage the diameter of the microscopic field was definitely determined. In counting, the slide was placed on the stage and, beginning at the upper right hand corner of the slip, the slide was moved across the field of view the exact width of the slip. The number of spores found present was then recorded and the slide moved up the diameter of the field, when another count was made. This was continued until the entire area of the slip had been gone over and all the spores present in the drop had been recorded. The sum was then multiplied by the number of drops found necessary to make a single cubic centimeter, the product being the total number of spores present in a cubic centimeter. Ten drops were counted from each collection, the number of spores per cubic centimeter determined, and the average number per cubic centimeter multiplied by the total number of cubic centimeters in the flask, gave the number of spores to each collection (approximately). The results obtained are presented in the appended table. (Table II.)

TABLE II.

Showing the Number of Smut Spores Obtained From the Foliage of Various Plants During the Early Part of September, 1915

Collection No.....	Date of collection, Sept...	Location.....	Plant.....	No. of leaves.....	Total No. of spores.....	Ave. No. of spores per leaf.....
1	9	College Orchard	Apple	25	1,865,266	74,610
9	9	College Orchard	Apple	25	3,631,792	145,272
3	10	Round Top	Maple	28	249,612	8,914
4	10	Round Top	Catalpa	15	693,594	24,669
5	11	Timber Claim S.W.	Box Elder	25	616,519	24,660
6	11	Timber Claim E.	Box Elder	25	769,557	30,422
7	11	Timber Claim C.	Box Elder	25	609,193	24,367
8	18	Kamiak Butte	Spiraea	30	266,475	8,882
9	18	Kamiak Butte	Balsamorhiza	6	28,353	4,725
10	18	Kamiak Butte	Symphoricarpos	22	31,317	1,423

When making the foliage collections, plants were selected which were located some distance from any wheat field or threshing operation. The leaves were taken from the various parts of the tree or plant, and no especial attempt was made to secure leaves showing a dense collection of dust.

Collections No. 1 and 2 were taken from two different trees, both situated in the northeast corner of the old orchard on the College farm. Collection No. 1 was from a large well-matured tree, with rather small leaves. No. 2 was from an adjacent tree which was younger, growing quite vigorously, and the leaves were somewhat larger. Both trees were on a southeast slope and situated in such a manner as to be quite well protected from the full force of the prevailing westerly winds. It is probable that bunt spores and dust would tend to settle at this particular point, which probably accounts for the large number of spores found on these collections. The nearest wheat field was at least a half-mile distant, and the nearest threshing operation much farther,

Collections No. 3 and 4 were taken from several trees located on the highest point of the College farm. These trees are not protected in any manner and receive the full force of the wind. The nearest wheat field was several hundred yards to the north and it is extremely doubtful if any bunt spores from this field ever settled on the foliage of these trees. The nearest wheat fields, west of this point, were two and one-half or three miles distant.

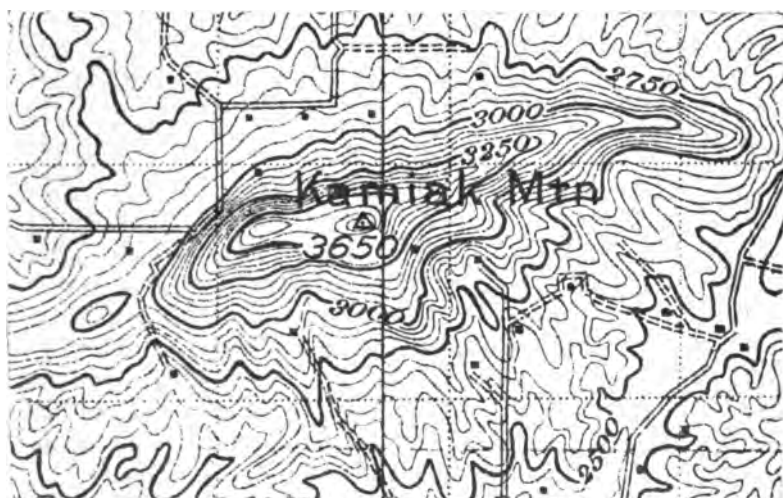


Fig. 1. Contour map of Kamiak and vicinity, photographed from the Pullman Quadrangle map of the U. S. Geological Survey, showing where foliage collections were made.

Collections Nos. 5, 6, and 7 were taken from a timber claim north of the College farm. This claim was located at the top of a hill and was surrounded on the north, west, and south sides by summer-fallow, while the east side only adjoined a wheat field. As the prevailing winds are mostly from the westerly directions it would indicate that if bunt spores could be obtained from the foliage within this claim, the summer fallow adjoining must be "seeded" equally as heavily. The foliage collections taken from the southwest corner, the center,

and the east side of the claim gave evidence of enough spores present, to warrant this conclusion.

Collections Nos. 8, 9, and 10 were secured from the highest ridge of Kamiak Butte at a point at least 1000 feet above the surrounding farms and two or more miles distant from the nearest wheat fields.

Water Spore Traps. The fact that the foliage of plants harbored bunt spores in large numbers at once raised the question as to the probable number of spores falling on a square inch of surface throughout the season. In order to determine this the use of the water spore-traps at once suggested itself. A description of these traps and their method of use is given in detail by Heald* et al., in their work on the air and wind dissemination of ascospores of the chestnut blight fungus.

Traps for 1915. Beginning September 1st and extending over a period of six weeks, ending October 14th, two spore-traps were stationed on the college farm at points distant from any wheat fields. Trap No. 1 was located at least one-fourth mile from the nearest wheat field and about one and one-half miles from the nearest threshing operation. Trap No. 2 was located on a point just south of Round Top (previously referred to), was equally as far distant from any wheat field or threshing operation, and with regard to elevation, was at least 150 feet higher than Trap No. 1. Collections were made weekly and all ordinary precautions were used to prevent the entrance of spores from other sources. The method of determining the approximate number of spores present in each collection was the same as that described for the foliage collections. The results are presented in the appended table. (Table III.)

*Heald, F. D., Gardner, M. W., and Studhalter, R. A. Air and wind dissemination of the ascospores of the chestnut-blight fungus. *Journ. Agr. Res.* 3:493-526. 1915.

TABLE III.

**Record for Spore Traps During Season of 1915, Showing Wind
Dissentiation of the Spores of Bunt**

Period Covered	Trap No. 1			Trap No. 2		
	Total No. of spores.....	No. of spores per sq. in..	No. of spores per sq. ft....	Total No. of spores.....	No. of spores per sq. in..	No. of spores per sq. ft....
Sept. 1-Sept. 8.....	155,175	3,978	572,832	119,262	3,058	440,352
Sept. 8-Sept. 16.....	58,806	1,507	217,008	63,591	1,630	234,720
Sept. 16-Sept. 23.....	21,720	557	80,208	25,977	666	95,904
Sept. 23-Sept. 30.....	17,028	436	62,784	12,995	333	47,952
Sept. 30-Oct. 7.....	4,926	126	18,144	2,475	63	9,072
Oct. 7-Oct. 14.....	12,078	309	44,496	8,712	223	32,112
*Total number of spores ... 269,733				 233,012		
Total number per sq. in... 6,916				 5,974		
Total number per sq. ft... 995,904				 860,256		

*The area of the traps was found to be 39 sq. in.

Traps for 1916. With the approach of the harvest of 1916, it was decided to place the water spore-traps out earlier in the season and if possible, run them later.* On August 16, three traps were stationed on the College farm, and weekly collections made for a period of eleven weeks, ending November 1st, when the temperature conditions no longer warranted their continuance. Traps. Nos. 1 and 2 occupied the same positions as during the year 1915, while trap No. 3 was stationed on the College Pathologium in a rather sheltered position. Trap No. 1 was equally as far distant from any wheat field or threshing operation as during the season of 1915, while trap No. 2 was but a quarter of a mile north of a very smutty field of wheat. Trap No. 3 was located in a summer fallow field, which for a number of years had been an old raspberry patch. To the south of the trap, but a few yards distant, was located some of the experimental plots used in growing spring wheat. All traps were set when harvest was at its height and about two weeks before any threshing operations began in the immediate vicinity. However, threshing and combine harvesting were at their height in the central part of the state, north and west of the College farm. It was our object to ascertain, if possible, the probability of wind dissemination from points 50 to 75 miles distant, the period of maximum dissemination in the immediate vicinity and the probable duration of the period of dissemination. Our results are recorded in the appended table. (Table IV.)

TABLE IV.
Record for Spore Traps During the Season of 1916

Trap No. 1			
Period Covered	No. of spores for the week	No. of spores per sq. in.	No. of spores per sq. ft.
Aug. 15-21	62,483	1,602	230,688
Aug. 22-28	143,866	3,688	531,072
Aug. 29-Sept. 4	200,000*	5,128	738,432
Sept. 5-11	420,732	10,788	1,553,472
Sept. 12-18	212,512	5,449	784,656
Sept. 19-25	52,896	1,356	195,264
Sept. 26-Oct. 2	40,194	1,030	148,320
Oct. 3-9	15,225	390	56,160
Oct. 10-16	12,931	330	47,520
Oct. 17-23	6,467	165	23,760
Oct. 24-30	11,866	304	43,776

Totals	1,179,172	30,235	4,353,840
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*Estimated.

Trap No. 2			
Period Covered	No. of spores for the week	No. of spores per sq. in.	No. of spores per sq. ft.
Aug. 15-21	43,343	1,111	159,984
Aug. 22-28	155,261	3,978	572,832
Aug. 29-Sept. 4	146,421	3,754	540,576
Sept. 5-11	520,142	13,362	1,924,128
Sept. 12-18	250,000*	6,410	923,040
Sept. 19-25	164,867	4,227	608,688
Sept. 26-Oct. 2	21,309	546	78,624
Oct. 3-9	19,348	496	71,424
Oct. 10-16	15,578	399	57,456
Oct. 17-23	6,467	165	23,760
Oct. 24-30	11,866	304	43,776

Totals	1,358,736	34,839	5,016,816
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*Estimated.

Trap No. 3			
Period Covered	No. of spores for the week	No. of spores per sq. in.	No. of spores per sq. ft.
Aug. 15-21	43,751	1,121	161,429
Aug. 22-28	200,108	5,130	738,720
Aug. 29-Sept. 4	319,725	8,198	1,180,512
Sept. 5-11	318,303	8,161	1,175,184
Sept. 12-18	188,602	4,835	696,240
Sept. 19-25	530,602	13,605	1,959,120
Sept. 26-Oct. 2	37,085	950	136,800
Oct. 3-9	21,344	547	78,768
Oct. 10-16	13,212	338	48,672
Oct. 17-23	5,379	137	19,728
Oct. 24-30	5,440	139	20,016

Totals	1,683,551	43,161	6,216,048
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Average No. of spores per trap for the season	1,407,153
Average No. of spores per sq. in. for the season	36,113
Average No. of spores per sq. ft. for the season	5,162,234

An examination of the records from the spore-trap collections shows for the season of 1915 that the maximum spore-fall occurred previous to or during the first week of September, since there was a gradual decline in the number of spores falling on each square foot of surface following the first week of record.

For the season of 1916 there is a general agreement in the results from the traps located at the three different stations. During the first three weeks from Aug. 15 to Sept. 4 there was a gradual increase in the spore-fall, the maximum fall occurring in each case during the week of September 5-11. It is worthy of note that this week was also one of high wind velocity (see Fig. 2). Following the maximum there was a gradual decline in the spore fall through the last weeks of September; during the month of October, spores were still present, but in greatly reduced numbers. It has been shown in our experimental plantings that the highest per cent of smut infection occurred during the month following the maximum spore fall.* During this period there was plenty of moisture, the temperature conditions were favorable for smut, and the abundance of smut spores in the soil, gave as high as 41 per cent of smut from clean treated seed. These results point to the conclusion that wheat seeded in summer fallow during the period following the maximum spore-fall (last of September and first of October) is likely to be heavily smutted.

RELATION OF CLIMATIC CONDITION TO THE SMUT SHOWERS

Wind Intensity and Velocity. The climatic conditions of the Palouse country, previous to, including, and a few weeks following the threshing season are especially favorable for the wide-spread dissemination of the spores of stinking smut. The period is invariably characterized by bright sunshine, a very slight or often no rainfall, and a rather high wind velocity, especially at certain periods. The typical Palouse dust storm

*Heald, F. D. The stinking smut of wheat. Pop. Bul., Wash. Exp. Sta. 116:10-11. 1918.

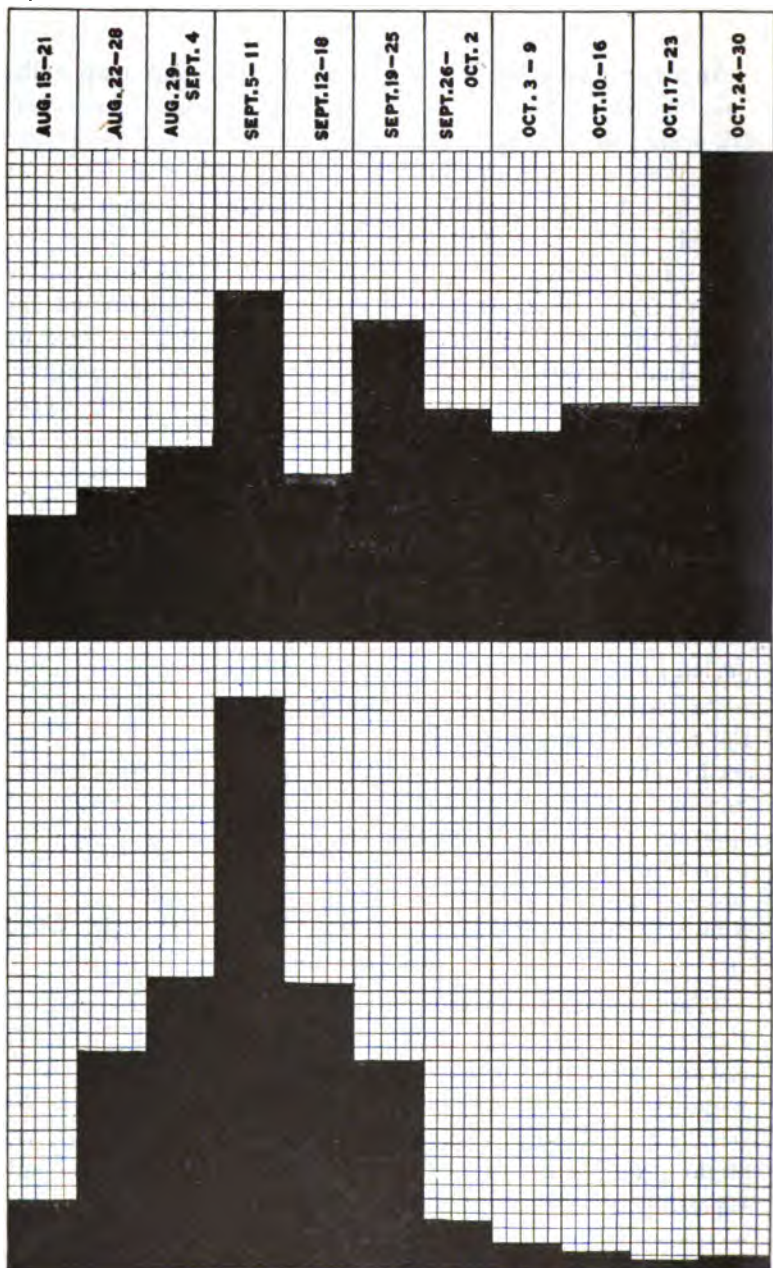


Fig. 2. Diagrams showing the spore fall and wind velocity from August 15 to October 30, 1916. The lower figure represents the spore fall, based on the total number of spores collected, and each square represents 2000 spores; the upper figure shows the wind velocity based on the average number of miles per day for 24 hours, for the week covered. Each square represents two miles. Diagram

is the culmination of a period of high wind velocity. This combination of factors makes the wheat straw very dry and brittle as well as causing a pronounced desiccation of the smut balls. The operators of threshing outfits take advantage of these dry conditions and run the separators at a very high rate of speed. This naturally causes the complete breaking up and crushing of the greater number of the smut balls, and as all machines are equipped with wind or fan stackers, great numbers of smut spores are thus shot into the air, and must ultimately find a resting place on either adjacent or distant fields.

Taking these facts into consideration it is interesting to note the relation of the wind velocity to the fall of the smut spores. The Division of Soils of the Experiment Station very kindly furnished us the wind records, covering the period during which the spore traps were set for the season of 1916. The results are graphically represented in the accompanying illustration. (Fig. 2.)

Rainfall. As previously mentioned there is a very small amount of rain during the harvesting and threshing season. The accompanying table (Table V) gives the rainfall for Pullman from June to October during the last three seasons.

TABLE V.
Rainfall in Inches at Pullman, June to October, 1915-1917

Month	1915	1916	1917
June	0.53	2.34	0.56
July	0.77	0.45	0.00
August	0.00	1.24	0.00
September	0.63	0.68	0.84
October	1.23	0.35	0.00

It may be noted that the season of 1917 was exceptionally dry, with a total of only .84 inch of rain during the four months covering harvesting and threshing operations in Eastern Washington and adjacent territory. Even during 1916, when the rainfall was above normal for the period, the conditions were still very favorable for the wind dissemination of smut. We must conclude then that the average weather conditions which prevail in the wheat belt of Eastern Washington are conducive

to a wide-spread wind dissemination of the spores of bunt. Combine with this wide-spread scattering of smut a farming system which includes summer fallow and fall seeding and we have the explanation for the smut menace of Eastern Washington.

SUMMARY

Seed treatment, the effective practice for the control of bunt or stinking smut of wheat in other wheat-growing sections, has not been effective for winter wheat in the Palouse country.

Bunt is one of the cereal smuts in which the infection takes place only through young seedlings, either from seed-borne spores or from spores already in the soil.

The possibility of a wind-dissemination of the spores of bunt has been recognized. It has been shown that wind-borne secondary spores or sporidia play no part in the spread of smut, since there is no spread of smut from an infected to an uninfected field during a single season. Scattering of spores from smutted heads previous to harvest is of minor consequence, but during the threshing operations the smut balls are broken up and much of the smut dust is carried out through the stacker. Much of this smut dust must ultimately come to rest on the surrounding fields.

The wide-spread wind-dissemination of the spores of bunt was suggested by the visible clouds of smut dust which issue from threshing machines whenever the run is in a smutty field; the presence of smut spores on vegetation distant from any threshing operations; the production of smutty wheat when clean treated seed was sown on land, which had not previously produced a crop of smutty wheat; and also by the general ineffectiveness of seed treatment for fall-sown wheat.

Positive evidence of this widespread dissemination of the spores of bunt has been obtained by the microscopic analyses of the washings of foliage taken from stations distant from any threshing operations. This was further substantiated by the use of water spore-traps, which have made possible the de-

termination of the actual number of spores falling on a given area.

During the threshing season there is a "smut shower" or spore-fall in the vicinity of Pullman, which begins in August, increases to a maximum and gradually subsides. During the season of 1916 the maximum fall occurred from the 5th to the 11th of September. The exact time of the maximum will depend in part on the location, the period when threshing operations are the most numerous, and also upon climatic factors.

The dry conditions which prevail during the threshing period, together with frequent winds of high velocity, and a farming system which includes summer fallow and winter wheat, have combined to make wheat smut especially severe in the Palouse country.

The greater amount of winter wheat is seeded in summer fallow which has received countless numbers of wind-blown spores; the maximum amount of seeding generally follows the period of maximum spore-fall, and at this time both temperature and moisture conditions are especially favorable for smut.

U. C. L. A. DUPLICATE

UNIVERSITY OF CALIFORNIA
AT LOS ANGELES

APR 25 1934

STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIRECTOR'S OFFICE

**TWENTY-EIGHTH ANNUAL
REPORT**

For the Year Ending June 30, 1918

BULLETIN NO. 153

January, 1919

**All Bulletins of this Station sent free to citizens of the State on
Application to Director**

LETTER OF TRANSMITTAL

Pullman, Washington, January 18, 1919.
Honorable Ernest Lister, Governor,
Olympia, Washington.

Sir:

I have the honor to submit herewith the Twenty-eighth Annual Report of the State Agricultural Experiment Station, covering the work of this Station and Sub-Stations for the year ending June 30, 1918.

Very respectfully,

GEO. SEVERANCE,
Acting Director.

Board of Regents

Wm. Pease, President	Seattle
E. O. Holland (President of the college) Secretary ex-officio, Pullman	
W. A. Ritz	Walla Walla
A. D. Dunn	Wapato
R. C. McCroskey	Garfield
E. T. Coman, President since April, 1918	Spokane

Experiment Station Staff

Geo. Severance, B. S.	Acting Director and Agriculturist
O. L. Waller, Ph. M.	Irrigation Engineer
A. L. Melander, Sc. D.	Entomologist
O. M. Morris, M. S.	Horticulturist
Geo. A. Olson, M. S.	Chemist
W. T. Shaw, M. S.	Zoologist
E. G. Schafer, M. S.	Agronomist
Wm. Hislop, M. S.	Animal Husbandman
F. D. Heald, Ph. D.	Plant Pathologist
J. W. Kalkus, D. V. S.	Veterinarian
M. A. McCall, M. S.	Dry Land Specialist
F. J. Sievers, B. S.	Soil Physicist
E. G. Woodward, M. S.	Dairy Husbandman
T. J. Murray, M. S.	Bacteriologist
F. L. Pickett, Ph. D.	Botanist
E. F. Gaines, M. S.	Cerealist
Henry F. Holtz, M. S.	Assistant Soil Physicist
C. H. Hunt, M. A.	Assistant Chemist
O. E. Barbee, B. S.	Assistant in Crops
Anthony Spuler, B. S.	Assistant Entomologist
Bliss Dana, M. S.	Assistant Plant Pathologist
R. P. Bledsoe, M. S.	Supt. Waterville Substation
H. N. Coleman, B. S.	Superintendent of Advanced Registry Testing
E. S. Robertson, M. S.	Assistant Horticulturist

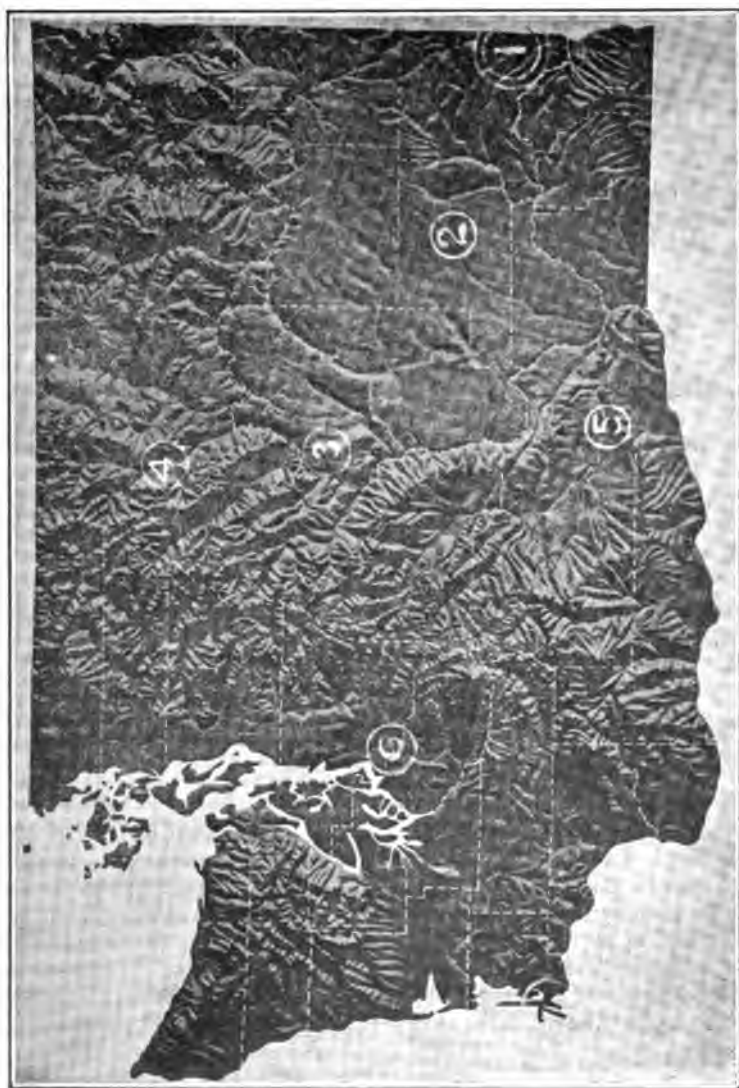


Fig. 1—Map of Washington, showing location of Agricultural Experiment Stations.

MAP OF WASHINGTON, SHOWING LOCATION OF AGRICULTURAL EXPERIMENT STATIONS

1. The main experiment station is located at Pullman, the seat of the State College, where the rainfall averages approximately 22 inches per annum. A farm of over 500 acres and the principal scientific laboratories are maintained here. Work on the more fundamental problems or those that require the use of laboratories and expensive equipment is carried on principally at Pullman.

2. The Adams Branch Station at Lind consists of 320 acres of typical soil and is devoted entirely to problems pertaining to the dry belt of Washington. The rainfall at Lind averages about 10 inches per annum.

3. The Waterville Branch Station consists of 220 acres of leased land and is devoted primarily to a study of forage problems and to an effort to develop a more diversified and permanent system of agriculture under the rainfall conditions prevailing in that region, which averages about 13.5 inches per annum.

4. The Winthrop Station consists of a five-acre tract with stock sheds and yards and is devoted exclusively to a study of the goitre disease of animals.

5. The Prosser Irrigation Station consists of 205 acres of unimproved land selected under authority of the 15th legislature as a site for an experiment station to study the many problems that are confronting the irrigation farmers. An option has been secured on this tract and it is being cleared and leveled with funds donated by the Prosser people. Its final purchase and further development depend upon an appropriation from the 16th legislature for that purpose. The importance of developing this experiment station may be appreciated from the fact that Yakima and Wenatchee Valleys alone produced in 1918 over \$30,000,000 worth of irrigated products and that Yakima Valley lost from the codling moth alone over \$2,000,000. Its importance may be further appreciated from the fact that the present irrigated area in Washington is only a small percentage of what may ultimately be brought under irrigation.

6. The Western Washington Experiment Station is located at Puyallup, where the average rainfall is about 45 inches per annum. It consists of 90 acres of typical valley soil and hill land and is devoted to a study of Western Washington problems.

7. The cranberry station is located at Ilwaco and is devoted entirely to a study of insects injurious to cranberries, and is maintained co-operatively by the State College of Washington and the Bureau of Entomology of the U. S. D. A.

TWENTY-EIGHTH ANNUAL REPORT

WASHINGTON AGRICULTURAL EXPERIMENT STATION

The work of the Experiment Station was very materially affected during the past year by the war. It was so shaped as to meet the great need for maximum production, and much of the time of several experiment station men was devoted to those activities which best would further the program of the state and nation.

The U. S. Department of Agriculture assigned five entomologists to the Extension Department of the State College and Dr. A. L. Melander, Entomologist of the Experiment Station, was appointed project leader for Washington. The government also assigned four wheat smut specialists to the Extension Department of the State College and Dr. F. D. Heald, Pathologist of the Experiment Station, was appointed project leader for Washington. Professor O. M. Morris, Horticulturist of the Experiment Station, was appointed project leader in horticulture.

Professor E. G. Woodward, Dairy Husbandman, Professor F. J. Sievers, Soil Physicist, and Professor E. G. Schafer, Agronomist of the Experiment Station, each devoted considerable time to the work for maximum production. Various members of the staff also devoted more time than usual to preparing press material. A series of articles prepared by members of the staff was run in nine of the leading papers of the state for several months.

Dr. J. S. Caldwell, By-Products Specialist, devoted the greater part of his time during the fall of 1917 as adviser to several companies in the Northwest, who were erecting by-product factories. One month during the fall was given to the Bureau of Chemistry, U. S. Department of Agriculture, upon request.

late in December, he resigned to enter the employ of the Bureau of Plant Industry.

The time of these men was diverted to extension work, as it was felt that they thus could render greater immediate service in the war emergency.

The unusual demand for trained men resulted in some resignations, several of which were for the purpose of engaging in United States government emergency service. Both on account of the shortage of help and of the unusual cost of both labor and supplies, it was necessary to suspend temporarily several projects. No funds were assigned to the Divisions of Animal Husbandry, Dairy Husbandry, and Irrigation Engineering, it being felt that the specialists in these divisions could render greater immediate service through extension work.

Changes in Staff.

Dr. J. S. Caldwell, By-Products Specialist; Wm. Hislop, Animal Husbandman; M. A. Magoon, Bacteriologist; A. B. Nyström, Dairy Husbandman; C. A. Thompson, Assistant in Soils, Adams Branch Station; F. W. Allen, Assistant Horticulturist; H. M. Woolman, Assistant Plant Pathologist, and M. A. Yothers, Assistant Entomologist, resigned during the year.

The following appointments were made: E. G. Woodward, Dairy Husbandman; T. J. Murray, Bacteriologist; R. P. Bledsoe, Superintendent Waterville Sub-Station; Anthony Spuler, Assistant Entomologist, and H. N. Colman, Superintendent of Advanced Registry Testing. Bliss Dana was transferred from Assistant in Bacteriology to Assistant in Plant Pathology.

Reports by Divisions

DIVISION OF ANIMAL HUSBANDRY

No funds were appropriated to this Division for the fiscal year just closed, but the following investigations were made through the aid of college students and the use of the college live stock.

Feeding Value of Feed Peas vs. Barley.

An experiment was conducted to determine the fattening value of field peas as compared with barley when supplemented with tankage and oil meal. Fifty-one shoats, bred by the State College of Washington, consisting of pure bred Duroc Jerseys, Poland China-Berkshire cross breeds, and Poland China-Duroc Jersey cross breeds were used. For comparison they were divided into four lots. The feeds used included cracked or split peas, common, beardless rolled barley, shorts, oil meal and tankage guaranteed to contain 60 per cent protein. The experiment continued 49 days during January and February, with the weather quite unfavorable for good feeding results.

The following table shows the rations fed, total grain consumed and total gains for each lot.

	Lot 1	Lot 2	Lot 3	Lot 4
	60% Barley 30% Shorts 10% O. M.	60% Peas 30% Shorts 10% Tankage	60% Peas 30% Shorts 10% O. M.	60% Barley 30% Shorts 10% Tankage
No. of hogs on test....	13	12	13	13
Initial weight per head (average)	99.77	107.33	107.84	100.69
Final (average)	160.38	184.75	162.77	169.62
GAIN IN LBS., TOTAL	788.00	929.00	714.00	896.00
GRAIN, LBS., TOTAL	3765.00	3818.00	3100.00	3820.00
Grain per lb. gain	4.77	4.10	4.34	4.26
Shrinkage in shipment to Stanton Packing Co., Spokane, per cent	11.66	16.75	18.50	16.63
Dressing per cent by lots	82.00	82.70	80.10	83.00

The feeds were assigned the following values per ton: peas, \$40.00; rolled barley, \$40.00; shorts, \$27.00; oil meal, \$50.00; tankage, \$50.00.

A study of the above figures indicates the following:

1. That peas and protein supplement such as tankage and linseed oil meal are superior to barley and a protein supplement, such as tankage and linseed oil meal.

2. That tankage, which is an animal protein, is superior to linseed oil meal, which is a vegetable protein, when fed to fattening hogs, in conjunction with barley or peas.

3. That a ration of peas, shorts and tankage ranks first; barley, shorts and tankage ranks second; peas, shorts and oil meal ranks third; and barley, shorts and oil meal ranks fourth in net profit and in the amount of grain required per hundred pounds of gain.

Relation of Breed and Age of Service to Prolificacy.

A study of the records of the college herd of swine of 1908 to 1916 was made to determine the relation of breed and age to prolificacy. The following is a summary of the facts obtained:

In Duroc Jersey swine, the total number of pigs under consideration was 400 and the average litter for that period was 7.143 pigs.

In Poland China swine, 479 pigs were studied and the average litter was 7.15 pigs.

In Berkshire swine, the number of pigs studied was 331, and the average litter was 6.245 pigs.

In Tamworth swine the number of pigs studied was 127 and the average litter was 7.94 pigs.

The above figures on the relative prolificacy of breeds at the State College of Washington indicates Tamworth, first; Poland China, second; Duroc Jersey, third; and Berkshire, fourth.

In this work it is also brought out that the size of the litter increases as the age of the sow increases, up to four years. Sixteen yearling sows produced an average litter of 6.12

pigs; 17 two-year-old sows, an average litter of 7.7 pigs; 10 three-year-old sows, an average litter of 7.8 pigs; and four four-year-old sows an average litter of 7.9 pigs.

DIVISION OF BOTANY

The Division of Botany has been of direct service to the farmers of Washington and adjoining states through the identification of weeds and native plants and the testing of seeds. The inquiries along these lines have increased to more than a thousand a year.

Investigations of weed distribution in the state, records of the introduction or spread of new weed pests and plans for the practical study of means of eradicating weeds, have been pursued. Study of weed habits and control will be greatly aided through the use of an area on the College Farm set aside this year as a weed garden. A special study of the wild oats situation in Washington has brought in valuable information concerning the limiting of this weed's range by rainfall, and concerning the varieties found in the state.

In conjunction with the Division of Farm Crops there is in preparation the first of a series of bulletins containing descriptions, distribution data and suggestions for the control of the serious weed pests of the Northwest.

DIVISION OF BACTERIOLOGY

Legume Culture Work.

In co-operation with the Division of Farm Crops, inoculation material for legumes to the amount of 11,693 acres, has been furnished to farmers. The work has paid for itself. Last year these cultures were sent out in sand. A little complaint was heard because of the damaging effect of the sand on the drills. This year, as a result of some laboratory investigations by C. A. Magoon, cultures have been sent out in bottles on agar media. The results of the sand as an inoculum have met with marked success in the field. The field results from the use of the new method of using agar media as an inoculum have not yet been obtained. Methods are still

in an experimental stage and considerable work must be done in order to place the work on a firm scientific basis. A full time assistant should be employed to devote his entire time to practical and investigational legume work. The inoculation of the soil of Eastern Washington is a work well worth while.

Bovine Tubercular Bacillus.

This work was outlined and started by C. A. Magoon. A bulletin, "Isolation and Cultivation of Bacterium Tuberculosis on a Synthetic Medium," was published in 1918. Because of the pressure of the legume culture work, no work was done on the project last year. Work has been started and is now under way with a view to completing this project.

The Effect of Straw on the Soil.

It has been observed that the addition of straw to the soils of Eastern Washington causes a decrease in the following crop yield. The above named project was taken up in co-operation with the Department of Soils with the view to determine the cause of this decrease in yield and to devise, if possible, some method of returning humus to the soil in the form of straw without ill effects.

Enough experimental data has not yet been obtained to draw conclusions. However, from the results thus far secured it seems that the addition of straw between one-tenth per cent and seven-tenths per cent stimulates nitrification, or the ability of the soil organisms to form nitrates. Between seven-tenths per cent and two per cent the straw inhibits nitrification and above two per cent, the addition of straw actually causes a decrease in the nitrate content of the soil. The nitrogen in the last case, however, is only temporarily lost to the plant as a food. It is transformed to protein nitrogen.

Miscellaneous Analyses.

Fifty-eight samples of water have been analyzed for the citizens of the state east of the Cascades. Five examinations have been made for the presence of the tubercular bacillus in

sputum; one for the presence of the tubercular bacillus in faeces; one for the presence of the tubercular bacillus in milk; 15 examinations of diphtheria swabs; five urine analyses and seven gonococcus examinations have been made.

DIVISION OF CHEMISTRY

The station chemist is also state chemist by virtue of his office and is, therefore, obliged to supervise a great deal of analytical work for the State Department of Agriculture in the control of foods, feeds, fertilizers. Some of this work has been particularly pressing, owing to war conditions and has, therefore, demanded more than usual attention. Furthermore, the unusual demand for chemists during the war has forced the station chemist to run very short handed, making it impossible to do the usual amount of station work. Work was temporarily suspended on "the function of sulphur as plant food." "Co-operative study of methods of analyses with the Association of Official Agricultural Chemists," and "the relation of soil types to composition of wheat."

The following is a summary of results obtained with the projects studied:

The Baking Qualities of Flour.

This project has been studied under three main heads: (a) influence of electrolytes on baking quality, (b) the use of substitutes for wheat flour on baking quality, and (c) a study of the physical properties of gluten and its possible bearing on the baking quality of flour.

(a) There are a number of preparations sold on the market which are used in combination with other materials for the purpose of improving the quality of the dough and ultimately with the object of improving the loaf of bread. Among such preparations is one known as Arkady Yeast Food, which patented preparation consists of calcium sulphate, ammonium chloride, potassium bromate, and a flour filler. This preparation, when used in conjunction with the other necessary ingredients, is claimed to save yeast and flour and increase the volume of the loaf of bread.

Investigations indicate that the Arkady Yeast Food shows beneficial effects with some flours, while with others no results were observed. In no case were all of the benefits claimed from the use of such materials observed in any one flour.

(b) Flour substitutes were studied with flours made from oats, barley, rice, yellow and white corn, apples, alfalfa, soy beans, but more especially with field peas and soy bean cake used in various combinations with wheat flour. The field peas used were of the Bangalia and Amraoti varieties. The Bangalia possesses a bitter principle which we found to be present in the hull and is removed in the process of milling. The soy bean cake which we used is the kind that is used for feeding stock and contains from six to eight per cent of oil instead of 16 to 18 per cent of oil, which is present in the original grain.

The advantage in the use of materials such as pea flour and soy bean flour lies in the fact that these materials contain considerably more protein than is found in the common cereals. The peas contain 25 per cent of protein and the soy bean cake contains about 46 per cent of protein. Cottonseed flour is also high in protein but not as high as soy bean cake. With the use of these materials it was thought that a saving in the consumption of meat could be made and at the same time meet the body requirements for protein. Legume flours should also be valuable as a food for people suffering from diabetes, owing to their low starch content.

Many plans were devised and worked out with the view of increasing the volumes of the combination of flour breads. Experiments were conducted with varying amounts of electrolytes, sugar, different kinds of sugar, varying amounts of yeast and also with combinations of the cereals other than wheat flour. In some of the experiments gluten was added. It was found that the volume of the loaf could be held to a size obtained from the use of wheat flour alone if not more than 10 per cent of pea flour or other substitute cereal flour were used. With the use of 15 per cent of pea flour, the vol-

ume of the loaf decreased five per cent, and with 20 per cent of pea flour the volume decreased 10 per cent. In other words, the volume of the loaf was inversely proportional to the amount of substitute used over 10 per cent. The results for soy bean cake flour and all other cereal substitutes gave similar results.

The flavor of the pea flour bread is very good. The crumb is of a greenish cast, which can not be regarded as objectionable. The soy bean cake flour does not taste as good as the pea flour bread and the color of the crumb is of a yellowish tint. Apple flour gives to the bread an acrid taste. The color of the apple flour crumb is of a brown hue, similar to that obtained in brown bread. The bread made from alfalfa flour tastes of weeds and the color of the loaf is objectionable. The results of these investigations are encouraging and justify further investigations to determine the extent to which substitutes may be used to advantage in peace times.

(c) Studies on physical properties of gluten indicate that the physical properties of the gluten of a given sample of flour are not entirely inherent, but are determined to a large extent by certain chemical composition which may be determined largely by environmental factors.

Influence of Cultivation on Nitrogen Content.

Winter varieties of wheat studied showed an average nitrogen content under cultivation of 2.86 per cent and without cultivation of 2.87. Spring varieties showed an average nitrogen content of 2.77 per cent with cultivation and 2.73 per cent without cultivation. These results would indicate that cultivation for this season gave practically no results in either direction. They may be due to the fact that the experiments were conducted on land that has been kept in a high state of cultivation for several years by the growing of peas every third year and by thorough tillage. In another field where the above varieties were grown in the ordinary way and without cultivation, the winter varieties averaged 2.47 per cent nitrogen and the spring varieties averaged 2.56 percent nitrogen.

This bears out former observations that the nitrogen content of wheat may be increased and the quality of wheat decidedly improved by keeping the soil in a high state of cultivation and well supplied with nitrogen through the growing of legumes.

Use of Gypsum and Land Plaster.

Co-operative tests with land plaster have been conducted on a few farms around Pullman. Selected areas of treated and untreated alfalfa were measured and weighed on the H. H. Curtis farm and an increase of over 200 per cent was noted on the treated plot. Similar results were reported by other co-operators, but unfortunately lack of labor made it impossible to measure and weigh accurately on the other farms.

This problem deserves further study, not only to determine the possibilities of increasing production by this means, but also to determine the ultimate effect upon the soil.

Studies on Pectin.

A method for recovering the pectin contained in fruit pomace has been devised that should prove of commercial importance. By this method, ammonium sulphate is substituted for the more expensive alcohol with the added advantage that the spent salt is valuable as a fertilizer.

There are several possibilities for the use of pectin besides that for the making of jelly, justifying more attention to the saving of this by-product. Cider and vinegar manufacturers could recover considerable pectin from the pulp that is thrown away after removing the cider.

Miscellaneous Analyses.

A large number of miscellaneous analyses have been made. Samples of feeding stuffs sent in by citizens were not analyzed, owing to the fact that the state law provides for an authorized inspector to sample commercial feed stuffs for official analyses. However, in a few cases where analyses were requested for good reasons, other than to determine the commercial status of the feed, such analyses have been made.

A number of analyses were made in cases of suspected poisoning. Numerous other routine analyses were made.

DIVISION OF DAIRY HUSBANDRY

No funds were assigned to this division for the past fiscal year, but the Station assumed responsibility for the Advanced Registry Testing in March, 1918.

Summary of Advanced Registry Testing for 1918 is as follows: Number of herds tested, 61; divided as follows: Holstein, 32; Jersey, 22; Guernsey, 4; Ayrshire, 3.

Number of different supervisors used, 35; averaging from 7 to 13 per month.

Tests conducted total 2523, as follows: 2-day tests, 2270; 7-day tests, 174; 14-day tests, 1; 21-day tests, 1; 30-day tests, 47; 60-day tests, 5; 90-day tests, 1; 100-day tests, 3; re-tests on high production, 21.

The number of tests conducted in 1918 is 81 per cent of the number conducted during 1917, which is very pleasing, considering the handicap of the war conditions and shortage of help.

Among the class leaders, nationally, the following Washington cows appear. The order of the records being name, number, milk production, average per cent, butterfat production, and rank.

Jerseys:—

Senior 3-year-olds:

Eminents Foxy Belle, 304982, 14920.6, 5.47, 816.65, 3rd.

Senior 4-year-olds:

Olympia's Fern, 252060, 16147.8, 5.81, 937.8, 1st.

Guernseys:—

Junior 2-year-olds:

Kulshan Hayes May Rose, 73318, 8261.20, 6.06, 500.45, 5th.

Ayrshires:—

The last Ayrshire Quarterly (1918) gives data on the following Washington cows:

Leaders in milk production:

Willowmoor Soncy Girl, 16707, 4.25, 709.60, Mature, 1st.

Willowmoor Etta 3d, 16621, 4.01, 666.06, Junior 2, 1st.

Leaders in fat production:

Lilly of Willowmoor, 22596, 4.23, 955.56, Mature, 1st.

Willowmoor Lily 5th, 14577, 4.55, 662.53, Junior 3, 1st.

Holsteins:—

The last "Blue Book," Vol. 29, gives the following Washington cows ranking first in their classes:

30-day records:

Von Heim Mary Hartog, 284404, 2054.9, 4.69, 46.383, Senior 2.

Von Heim Winnifred Colantha, 329334, 1925.4, 4.89, 94.164, Junior 2.

7-day records:

Von Heim Winnifred Colantha, 284404, 444.5, 5.33, 23.698, Junior 2.

365-day records:

Ormsby Segis Marie, 223321, 27025.7, 3.18, 859.63, Senior 3.

The Advanced Registry Testing is practically self supporting from the fees paid by the breeders for this work. From May 1, 1918, to January 1, 1919, nearly \$6000 has been paid out for the work from the fees received; the monthly average being from \$700 to \$750.

With the close of the war the future prospects are very encouraging as is indicated by the numerous letters of inquiry being received regarding the work. There are quite a number of breeders taking up official testing for the first time as well as many of the older breeders who temporarily discontinued official testing.

DIVISION OF FARM CROPS

In a report of the investigational work of the Division of Farm Crops, a single year's work is of little value by itself. The year's work therefore has been supplemented by adding data obtained in prior years in a number of cases. The experimental work being done is analyzed and interpreted so that farm practices may be benefited by it.

The work of variety testing which must continue to be an important part of the work as long as new varieties are being

introduced in the state, has been increased about 25 per cent. New introductions as well as new hybrids of exceptional promise, produced at the Experiment Station, are being compared with standard varieties in field tests. More extensive plans have been devised to distribute superior varieties of grains. Through the co-operation of the county agriculturists, their value is being checked up with other varieties in the various localities where superior grains are distributed.

Experiments are in progress which show definite possibilities of producing smut resisting varieties of wheat and oats by breeding. Definite information is being accumulated which throws considerable light upon the problem of what constitutes winter hardiness in wheat. Information is being gained on the comparative value of different crops for silage. Experiments are being conducted to determine methods of production by which clover and alfalfa seed may be profitably produced within the state. Crop rotation experiments are being started which should have a far reaching influence on the cropping system to be practiced in the future.

The division between the work of two years naturally comes with the harvest. As this report covers the work for the year ending June 30, 1918, it deals with the crop harvested during the summer and fall of 1917.

Variety Testing.

A summary of results to date indicate the following:

1. Hybrid 128, which was produced and distributed by the State College of Washington, is the best winter wheat under conditions that prevail at Pullman; Bluestem is the best spring wheat, except in the arid sections of the state, where Baart does better.

2. Banner oats, introduced direct from Scotland and distributed by the Experiment Station, is distinctly superior to all others in yield, in Eastern Washington. Abundance is a close competitor and has been distributed to some extent. Sixty Day is lowest in yield, both in 1917 and in the four-year average. White Bonanza ranks first for the Skagit Flats in Western Washington.

3. The coast barleys are the most satisfactory varieties to grow and will yield more pounds to the acre than any other grain crop. Winter barleys should not be recommended, as they are not winter hardy and on the average, the yield is 13 bushels less than spring barleys.

4. Bangalia is the best variety of peas in total yield, but on account of market discrimination and from the fact that Bluebell matures somewhat later, it may be more profitable where the seed is to be marketed or when planted with the later maturing varieties of oats for hay.

5. Mexican Red beans are by far the best variety for the Palouse country. Yakima Pinks are preferable in the warmer irrigated sections.

6. The best rate to seed corn varies with the season, ranging from two to five stalks per hill; three stalks being on the average the best during the years tested.

7. Chick peas, the sorghums and Soy beans are not to be recommended except in restricted districts of long season and high temperature.

8. Minnesota No. 2 rye is the best winter variety; Beardless is the best spring variety.

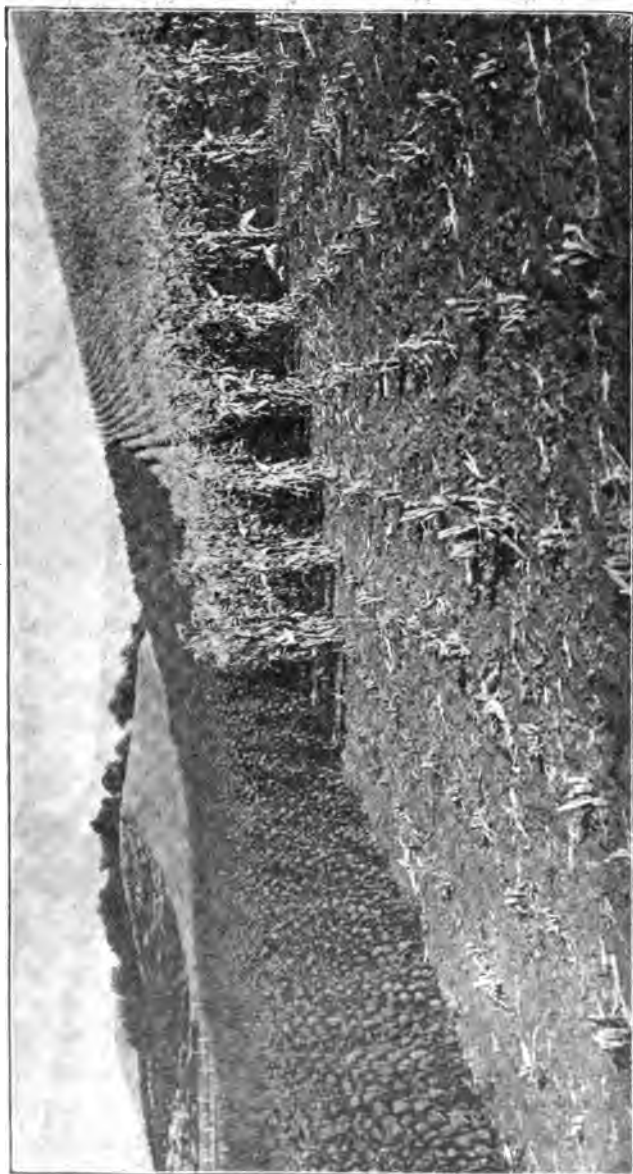
9. Minnesota No. 25 flax out-yields the best of the other four varieties tested by 45.7 per cent (two years average).

10. The date of seeding winter wheat experiment showed late August and early September seeding to give the highest yield in 1917. One season's results should not be accepted as conclusive.

11. The plots with various degrees of smutting were not conclusive in 1917, but a two-year average shows a decrease in yield in proportion to an increase in amount of smut produced.

Increase and Distribution of Seed.

More than 33 tons of pure seed, and bacteria culture prepared by the Division of Bacteriology sufficient for 11,693 acres of legumes, have been distributed throughout the state in 1167 different shipments during the year ending June 30, 1918. The standard maintained for seed sent out was kept



The Winter Hog Lot

Fig. 2—The Winter Hog Lot. On the left is a field of artichokes that produced 11.4 tons of silage per acre from the tops and 14.4 tons of tubers on the roots. The corn produced 71 bushels per acre. When the ground isn't frozen the hogs will dig and eat the artichoke tubers.

so high that more than 70 tons were discarded for feed or flour.

Inheritance Studies.

Definite information has been obtained on the inheritance of smut-resistance, winter habit, grain and glume color, sterility, beards and dwarfness of wheat. Considerable material has accumulated on the inheritance of various characteristics of wheat, oats, barley, corn, peas, rye, and forage plants which has not yet been compiled and interpreted.

Forage Investigations.

Turnips and rutabagas produce the largest tonnage per acre of the root crops. Winter wheat produced a larger tonnage of green forage for silage than any other single crop or combination in 1917.

Preliminary results indicates that the red clover seed can be profitably produced when proper spacing methods and proper time of cutting have been worked out. Work has been started to determine the possibilities of using a nurse crop in obtaining a stand of clover and alfalfa.

Cultivation and Rate of Seeding Wheat.

Wheat seeded in ordinary drill rows yields more than when the rows are spaced 12 to 18 inches apart. Cultivation is of material benefit to winter wheat, but decreases the yield of spring wheat.

Methods of Applying Manure to Wheat.

The average of 18 years tests with manure applied as top dressing on summer fallow wheat versus plowing under the same amount of manure for summer fallow show best results from top dressing.

Methods of Summer Fallowing.

The results of 18 years tests show best results from early plowed, well tilled summer fallow.

Crop Rotations.

Eighteen years tests comparing crop rotations including clover, straight wheat and summer fallow, cropping with

wheat every year with no fertilizer, and cropping with wheat every year with 10 tons of manure per acre applied annually indicate:

1. A quite marked and regular decline in yield under annual wheat cropping without manure with the yields at the beginning of the 18-year test bearing the usual relation to those on summer fallow.

2. That wheat seeded annually with an application of 10 tons of manure per acre yields as much now as at the beginning of the period and yields practically as much as the well tilled summer fallow plots, showing that summer fallowing is not necessary with the rainfall received at Pullman if the fertility of the soil can be properly maintained.

3. That in rotations that include clover and eliminate summer fallow, the yields of wheat are maintained nearly equal to the yields on well tilled summer fallow. Since the rotations used provide wheat half the time, the advantage of the rotation is apparent.

DIVISION OF HORTICULTURE

Orchard Pollination.

Tests were made of the self sterility of the Jonathan and Rome Beauty varieties of apples and of the influence of these on the setting of fruits by these trees when cross pollination was not permitted. Both varieties set a few fruits without cross pollination, when pollinated by the normal fall of pollen and distribution of pollen and by the work of bees. The fruits set on these trees contained very few seeds and a large proportion of seedless apples. The Jonathan apple produced on the tree which was inclosed by a tent and to which bees were admitted averaged 1.2 seeds per apple. Rome Beauty apples under the same conditions averaged one seed per apple. The Jonathan to which no cross pollination or insects were admitted during the blossoming period produced fruit which contained 1.9 seeds per apple. The Rome Beauty under similar conditions produced fruit that carried 4.8 seeds per apple. The Jonathan in the open orchard produced seven seeds per apple

and the Rome Beauty averaged 10 seeds per apple. No appreciable difference existed in the size or appearance of the fruits that were produced by self pollination and those produced in the open orchard.

Mendel's Law of Blackberry and Raspberry Hybrids.

The fruiting of a large number of blackberry and raspberry crosses developed the fact that the Evergreen Blackberry is the only variety which comes true to seed. The variation in the seedlings of the common varieties of blackberry and raspberries and their hybrids are existent in every part of the plant and fruit. The crosses within the specie will be eliminated from the work. No plants fruiting have shown indication of being worthy of consideration as a new variety for introduction into general use.

Winter Dessication of Fruit Trees.

The first year's work with trees grown in sand and given nutritive solutions to determine the influence of varying quantities of alkali and nitrates, has not given any indication that the cause of the trouble is a result of an unbalanced food supply in these particular food materials.

Relation of Soil Moisture to the Keeping Quality of Apples.

The work on this project was conducted along similar lines to the work of previous years. The results clearly indicate that so long as the moisture conditions of the soil are such as to produce normal fruit, the keeping quality of the fruit is not noticeably modified by that factor. The extremely large fruits have broken down in storage first and in most cases the fruit with an undersupply of color of the red varieties have broken down before those highly colored.

Orchard Cover Crops.

This work was continued along the lines reported in the last annual report. It is evident in the rainfall sections that late plowing under of the growing cover crop in the spring is the cause of unsatisfactory results in the use of such crops. Humus is developed at the expense of the fruit crop being pro-

duced and the indications are that only very limited value can be derived from cover crops in Eastern Washington in fruit producing orchards.

Renovation of Prune Orchards in Clarke County.

Work on this project consisted in starting fertilizer tests in five orchards in which nitrate of soda, ground blood and tankage and a mixture of nitrate of soda and ground blood and tankage were used. Results, although incomplete, indicate that the nitrate of soda is a very helpful fertilizer for the prune orchards of Clarke County.

Variety Tests of Garden Vegetables.

A study of the varieties of the potatoes grown in this state indicate that in Eastern Washington for early potatoes the Early Ohio and Early Rose are best. For the main crop the Burbank, Rural New Yorker, Gold Coin and American Wonder are very popular and profitable varieties. In Western Washington the Early Ohio and Early Rose and Irish Cobbler are the best early varieties. The Burbank, Pride of Multnomah and Rural New Yorker are the leading main crop varieties. In the irrigated sections the Netted Gem and Russet Burbank are the leading main crop varieties.

Frost Injury to Tender Plants and Fruit Tree Blossoms.

The work done on this project seems to indicate that resistance to frost injury is not correlated with the physical vigor of the plant, but in many cases seems to be inversely in proportion to the amount of new growth developed by the plant. Blossoms produced by the most vigorous plants are usually more easily killed than those produced by less vigorous plants. The cell tension existing in the plant at the time of a reduction of temperature to the danger point and the subsequent rise of temperature is probably the most influential factor determining the amount of injury done.

DIVISION OF IRRIGATION ENGINEERING

No funds were appropriated to the Division of Irrigation Engineering, the work of the Division being confined to personal aid in matters pertaining to irrigation engineering.

DIVISION OF PLANT PATHOLOGY

The work of the Division of Plant Pathology during the past year has resulted in marked progress on its three principal projects. The following are some of the more important results obtained:

Wheat Smut.

1. Normal grains from partially smutted heads do not transmit the disease.
2. Strong bluestone solution (1-1 formula) sprinkled on the seed very greatly reduced the infection from smut in the soil.
3. Early plantings (August) were practically free from smut, and gave good yields.
4. Replowing which had been suggested as a means of reducing smut increased rather than reduced the yield.
5. Smut loss is not accurately estimated by a head count.
6. Exhaust fans on threshing machines, if properly installed lessen the danger of explosions, improve the quality of the wheat and prevent much of the smut dust from passing out through the stacker.

Rhizoctonia Diseases.

1. Additional evidence has been obtained that tomato blight is caused by Rhizoctonia, and that the disease may be transmitted from the potato to the tomato.
2. The standard mercuric chloride treatment of seed tubers does not increase the yield of table stock, but should be used for the production of extra fancy or seed stock free from sclerotia.
3. Seed selection is of more value than seed treatment in the prevention of loss from Rhizoctonia.

Fire Blight.

Leaf invasions of *B. amylovorus* were produced by inoculation and a certain per cent led to twig blight by migration downward through the leaf petioles.

Powdery Scab.

Tests indicate that powdery scab on potatoes is comparatively harmless in Washington.

Potato Storage.

Investigations show that spindling sprouts of potatoes may result from poor conditions of storage.

Identification and Study of Miscellaneous Diseases.

This work has constituted the basis of the Plant Disease Survey which is carried on in co-operation with the Federal Plant Disease Survey. Specimens and inquiries have been received from all the adjacent states and Canada in addition to our own state. The number of diseases diagnosed on the basis of specimens sent to the Experiment Station has been as follows:

1915—500.

1916—370.

1917—394 to January 1, 1918.

A detailed report giving the results of these examinations is being prepared.

Some of the More Important Diseases.

No attempt will be made to list all of the diseases that were reported during the year. The following are some of the more important diseases that are new to the state according to all available records:

- 1 The aecidial stage of *Puccinia Graminis* on the barberry.
- 2 The internal black spot of cabbage.
- 3 A bacterial ear rot of corn.
- 4 Cottonwood scab due to *Fusicladium Tremulae*.
- 5 Cranberry rust due to *Pucciniastrum myrtilli*.
- 6 Cranberry rot due to *Fusicoccum Putrefaciens*.
- 7 Fig cankers caused by a *Botrytis* species.
- 8 Gooseberry fruit spot caused by *Phyllosticta Grossulariae*.
- 9 A bacterial blight of the blossoms of the white lilac.
- 10 Citrus canker on oranges imported from Japan.
- 11 Peony scab due to *Cladosporium peoniae*.
- 12 The bacterial blight of English Walnut.

A number of diseases are of increasing importance and demand investigation either as to control methods or etiology or both. These are in addition to the projects already under investigation. The following may be mentioned:

1. The crown rot of fruit trees. Investigation of cause and prevention.
2. Apple anthracnose. A further study of the life history of the fungus and experimental work of the control of the disease.
3. Fusarium rot of onions. Etiology and control.
4. The rough bark disease of both apple and pear.
5. The leaf roll and silver leaf of the prune. The cause of these troubles is uncertain and no remedial measures are known. The silver leaf disease of Washington has not been shown to be identical with the disease of this name in other regions.
6. The cause of clover failures in Western Washington.
7. The blight of alfalfa due to *Pyrenopeziza Medicaginis*.
8. The value of spraying for potato blight in Western Washington and the distribution of this disease.

DIVISION OF SOILS

Soil Moisture Project.

The results obtained from this project covering a period of six years on the Palouse soil show conclusively that the total moisture supply to the growing plant is not affected by variations in summer-fallow tillage. It has been found that there is sufficient precipitation every winter to leave the soil in a completely saturated condition in the spring of the cropping season even though the summer-fallowing has not been practiced. The distribution of moisture in the soil, however, is affected by summer-fallow and by variations in the methods of tillage practiced in that some plots showed a much higher moisture content than others in the surface foot of soil. The results showed also that the moisture in the surface foot of soil if held there during the warm portion of the year had a favorable effect upon nitrification as indicated by the

increase in the nitrate content of such plots. The yield of wheat varies almost in direct proportion to the nitrate content of the soil and consequently the conclusion has been reached that the system of tillage which will keep the largest amount of moisture in the surface foot of soil during the summer-fallow year is also the system that will produce the best crops.



Fig. 3—(6) No summer fallow—20.5 bu. wheat per acre. (3) Fall plowed, early spring disked and harrowed—52.7 bu. per acre. (8) Late spring plowed and harrowed—30.6 bu. per acre.

Crop Residue and Nitrification Project.

The practice of summer-fallowing on the soils of Eastern Washington has had a very destructive effect on the organic matter which in turn has had a detrimental effect on the physical condition of the soil. The maintenance of humus in the soil requires that crop residues, green manures or barn-yard manure be returned to the soil. These facts together with the experience that very unsatisfactory crop yields are often times obtained when an effort is made to increase the humus supply, have prompted this work.

A field of 36 plots was laid out to determine:—

1. Best time of year to return straw to the field.
2. Comparison between plowing under or surface dressing of straw.
3. Comparison of straw applied alone or supplemented with sodium nitrate.
4. Comparison of straw used on spring or winter grain.

Results obtained previously from the work on tillage plots have shown conclusively that nitrates in the soil are the limiting factor in crop production from the standpoint of fertility. The questions whether a commercial fertilizer containing nitrogen could be substituted for summer-fallow and whether such could be practically introduced in Eastern Washington need an answer. Plots were laid out to determine:—

1. Best time to apply a nitrogen fertilizer.
2. Amount of nitrogen to apply.
3. Comparative value of sodium nitrate and ammonium sulphate.
4. Comparative effect on winter and spring seeding.
5. Location in the spring of nitrates applied in the fall.

In connection with this work several fertilizer tests with sodium nitrate were conducted in co-operation with farmers on wheat fields in the vicinity of Pullman.

The season's results do not justify drawing conclusions without further tests.

Soil Fertility Project.

To determine the limiting factor in soil fertility 23 fertility tests were conducted in the field in co-operation with 17 County Agents. This work was supplemented by pot tests at Pullman, conducted on three different soil types with a total of 80 pots grown to oats and 30 pots grown to clover. The results from this work should prove invaluable as a means of giving definite information concerning the fertility and lime

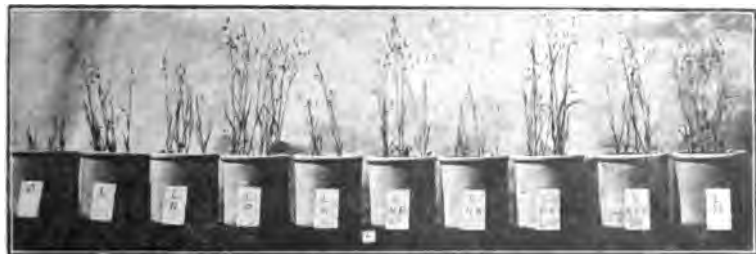


Fig. 4—A Western Washington soil—Melbourne series. A pot test which shows that the soil is in need of both phosphorus and lime, as indicated by the increased growth of oats produced on all pots that had phosphorus and lime applied.

requirements of at least a few of the important soil types in the State.

Lind Sub-station.

The Soils Department in co-operation with the Dry Land Sub-Station at Lind, Wash., is conducting tillage, fertilizer and crop residue experiments on 74 plots in duplicate. Thirty-six of these plots are devoted to tillage and on these moisture and nitrate determinations were made for the first time this year. Results indicated that there were very wide variations in the nitrate content of the different plots as affected by variations in tillage. In fact the variations in nitrates were greater than the variations in the total moisture content in the plots. This would tend to indicate that the available nitrogen supply, even in those dry land soils, may become a more direct limiting factor than the supply of moisture.

Twenty fertilizer plots were laid off in the spring of 1918 with the intention of determining the limiting factor of soil fertility, both from the standpoint of yield and quality of the product produced.

Eighteen plots were laid off to determine the value of crop residues and barnyard manure from the standpoint of time, manner and method of application.

Pot Work on Crop Residues.

Last year's report showed that an application of straw to soils in pots decreased the yield of wheat. This work was carried on again this year on another soil to check up last year's results. The following table gives the data:

Treatment	Grain gms.	Straw gms.	Total gms.
Control	5.60	16.75	22.35
Straw, 11 gms.	4.68	12.50	17.18
Straw, 22 gms.	4.65	10.00	14.65

These pots are in crop again this year so that the residual effect of straw may be determined.

Last year's report showed that when straw was applied to an alfalfa soil, which is ordinarily considered very productive, it had the same depressing effect on the yield, as is indicated in the data above. When, however, this same soil was cropped

the succeeding year the residual effect of the straw applied the preceding year was apparently beneficial, as indicated below.

Treatment	Grain gms.	Straw gms.	Total gms.
Control	4.26	12.00	16.26
Straw, preceding year, 11 grms.	5.68	13.20	18.98

In connection with this work the pot tests on crop residues and manure both supplemented with green alfalfa were continued. It was found that the residual effect of the crop residue in the second year was also beneficial, as indicated by an increased yield of wheat. In a general way it might be stated that the application of straw has a depressing effect on nitrification and that it takes almost a year's time before this effect is sufficiently overcome to bring the crop yields back to normal. After this depressing effect is overcome the crop residue has a beneficial residual effect.

Carbon-Nitrogen Ratio in Soils.

An effort was made to determine the effect of the growing of alfalfa on the carbon and nitrogen content of soils. Soil samples were obtained from the Palouse section and also from the irrigated fields in the Wenatchee and the Yakima valleys. The tables below show the difference in the carbon and the nitrogen content of soils grown to alfalfa as compared to soils under clean cultivation.

WENATCHEE SOILS

Time in alfalfa	Soil depth considered	Increase in nitrogen in lbs., per acre	Increase in carbon in lbs., per acre
3 yrs.....	5 feet.....	580 lbs.....	15,800 lbs.
3 yrs.....	4 feet.....	69 lbs.....	4,600 lbs.
20 yrs.....	5 feet.....	2,915 lbs.....	18,250 lbs.
4 yrs.....	4 feet.....	349 lbs.....	14,000 lbs.
— yrs.....	5 feet.....	784 lbs.....	18,100 lbs.

Yakima Soils

5 yrs.....	4 feet.....	1,115 lbs.....	2,265 lbs.
5 yrs.....	4 feet.....	87 lbs.....	3,485 lbs.
15 yrs.....	4 feet.....	1,516 lbs.....	19,689 lbs.
9 yrs.....	4 feet.....	854 lbs.....	4,008 lbs.
4 yrs.....	4 feet.....	1,254 lbs.....	4,356 lbs.
5 yrs.....	4 feet.....	296 lbs.....	
7 yrs.....	4 feet.....	923 lbs.....	1,917 lbs.

PALOUSE SOILS

12 yrs.....	4 feet.....	4,150 lbs.....	71,500 lbs.
4 yrs.vetch	3 feet.....	1,093 lbs.....	25,400 lbs.

Soil Sample Tests.

About 500 samples of soil were received at the laboratory and examined. These samples were submitted by farmers from all sections of the state, indicating that the service offered by this department is not only appreciated but is utilized. In order to be of best service, in this connection, however, the department should devote more time to detailed experimental work in the field.

DIVISION OF VETERINARY SCIENCE

Goitre Disease.

The work in this division has been confined to the one project, V. 6; Goitre and associate conditions in domestic animals. The major part of the investigation of these conditions was conducted as formerly at the temporary station located between Twisp and Winthrop, in the Methow Valley, Okanogan County.

It is gratifying to note that during the past year, experimentation with goats and sheep has yielded some extremely satisfactory and encouraging results. Three different lots of these animals which had previously given birth to goitred young, this year dropped perfectly normal young as the result of treatment with iodine, administered by different methods. The first lot was treated by giving two grains of potassium iodine daily throughout pregnancy; the second by injecting under the skin once a week throughout pregnancy, one-half mil. of tincture of iodine mixed with five mils. of water; and the third lot was treated by pouring one mil. of tincture of iodine on the back once a week throughout pregnancy. Results in all cases were uniform and the efficiency of iodine as an agent for the prevention of congenital goitre and hairlessness, at least in the case of goats, has been proven beyond a doubt. In these latter animals, it was possible to maintain absolute checks on our experimental subjects.

Constant experimentation during the past three years has failed to yield conclusive results in the case of hogs. Different varieties and sources of food and water given to sows during pregnancy, has failed to cause the farrowing of hairless pigs.



Fig. 5—A pair of stillborn and hairless kids affected with goitre. These were dropped by an Angora doe (No. 20) in the spring of 1917. No treatment was administered to this doe during pregnancy.



Fig. 6—A pair of normal twin kids dropped by the same Angora doe (No. 20) in the spring of 1918, after administration of one-half mil. of tincture of iodine mixed with five mills. of water under the skin once a week throughout pregnancy.

In practically all cases, sows at the Station have dropped normal pigs, and this without the administration of iodine. It is evident that hogs are much less susceptible to this condition than either goats or sheep.

A detailed comparative study has been made of the pathology of the thyroid glands of the various species of animals and this together with the results of chemical examination points to a like origin of goitre in goats, sheep and cattle, hairlessness in pigs and the condition commonly known as "weak colts."

DIVISION OF ZOOLOGY AND ENTOMOLOGY

The usual routine of identification of insects and other pests and of furnishing advice for their control has been greatly increased because of war-time interest in food production and conservation. The designation of the Entomologist as project leader in extension entomology and the assignment by the U. S. Bureau of Entomology of five entomological assistants has served as never before to correlate station with extension work and to carry to the public the basic investigations of this institution. Through this means this year we have informally been enabled to add to our knowledge of the work and control of such insects as the coulee cricket, strawberry root weevil and grasshoppers.

Cranberry Insects.

For several years certain newly introduced insects have been increasing to such an alarming extent as to threaten the cranberry industry of Southwestern Washington. Already several bogs have had their entire crop ruined. Preliminary surveys during 1917 showed that the main damage was done by the blackhead fireworm (*Eudemis Vacciniana*), which in its new environment had acquired habits remarkably different from its behavior in the East, being here destructive mainly to the fruit.

Since the cranberry growers petitioned the U. S. Bureau of Entomology likewise to engage in a study of their pests it

was deemed expedient to join forces and hence a formal contract was entered into for a co-operative study of cranberry insects in the region north of Ilwaco.



Fig. 7—Insectary at Seaview, Wash., used in the co-operative investigations on cranberry insects.

Among the results of this season's co-operative work may be mentioned the following:

1. The identification of the devastated species was verified, and its life cycle and fruit feeding habits investigated. It was ascertained that the times of greatest abundance of the larvae were the latter part of May for the first brood and the middle of August for the second, while unlike the eastern form, a partial third brood of larvae appeared during September.

2. Suggested methods of spraying were tested. These showed the necessity of using a spreader such as soap or glue with the insecticide. In general, better results were obtained with nicotine spray than with the customary arsenical.

3. Locally, a native weevil (*Geoderces Ineomptus*) was found destructive, and the cranberry girder (*Crambus Hortu-ellus*) was noted as widespread though causing relatively little harm.

Independently of the co-operative study the entomologist carried on some spraying tests in a heavily infested bog, to determine if the penetration system of spraying developed at this Station could be adapted to bog conditions. Inasmuch as the over-wintering eggs and hatching larvae of the fireworm occur exclusively on the underside of the leaves within a few inches of the ground it was deemed advisable to drive a horizontal flat spray among the matted vines instead of depending on the usual mist-spray settling down from above. This test apparently has given the keynote to future spraying procedure since the area so treated developed the fewest larvae of the bog.

Immunity of the San Jose Scale to Sprays.

In order to bring together under the same environment scale insects from the several regions of the state an attempt was made to transfer such scale insects to potted trees in the insectary building. While many thousands of scales in all were transferred, being lifted off by a fine camel's hair brush immediately after birth and laid on the potted trees, the experiment was unsuccessful. For some unknown reason the transferred scales remained naked throughout their life. Most of the scales died early in the experiment; a few, however, lived to develop some strands of white wax, which failed to agglomerate and form the protecting shell so characteristic of scale insects. Those that reached maturity did not reproduce in the artificial climate of the insectary. Absolute failure has repeatedly been met in trying to get the San Jose scale to thrive at Pullman, both out of doors and within the insectary, which is rather a commentary on the usual idea that the San Jose scale is the worst orchard pest.

A more successful venture was an exchange of infested trees between Clarkston and Wenatchee. These trees were treated with identical solutions of lime-sulphur and in line with our

previous results a greater resistance to the spray was shown by the Clarkston scales. During the spring months the extensive spraying tests of preceding years were repeated at Clarkston, Walla Walla, Yakima and Wenatchee. Counts one by one of many thousands of scales at definite intervals subsequent to the spraying showed as heretofore a marked degree of difference in resistance to the polysulphide sprays according to the provenience of the insects. Scales from Wenatchee were relatively highly susceptible, while those from Clarkston showed a striking resistance.

In connection with this work tests of many insecticides were made, which have an ultimate practical bearing. The highest grade of miscible oils used at five per cent strength proved much quicker acting and more efficient than the customary polysulphid sprays, but samples of one widely used brand obtained in different localities lacked uniformity to an astonishing degree. A dry form of lime-sulphur did not measure up to the liquid in efficiency and is far too expensive for recommendation. Lime-sulphur testing three degrees Beaume is usually as efficient as a stronger spray, but where scales show a resistance to this strength they are resistant likewise to a much greater concentration. In such cases it is advisable to use a good grade of heavy oil spray.

Taxonomy of Insects.

Some technical research on the classification of certain groups of insects has been carried on in the entomology laboratories. A paper dealing with *Drapetis*, a group of predatory flies, appeared in the Annals of the Entomological Society of America, Volume XI, pages 183-221 (June, 1918). A similar study of the related genus *Platypalpus* has been made and is ready for publication. A monographic review of the scavenger and dung flies belonging to the family Borboridae has been practically completed.

Biological Survey of Washington.

In informal co-operation with the Bureau of Biological Survey of the U. S. Department of Agriculture this division made

a survey of the base of Mount Adams and of the Wenas Valley, during the summer of 1917. The entomologist similarly was afield in insect scouting work, particularly in Western Washington, going from place to place by automobile so as to come into direct contact with the insect problem of that part of the state.

ADAMS BRANCH EXPERIMENT STATION

1917 was the first crop year on the Adams Branch Experiment Station. Crop conditions were on the whole unfavorable, the late, cool spring causing slow development, activity of wire worms thinning stands, and hot summer weather seriously affecting ripening grain.

Cereals.

Because of unfavorable weather conditions, no fall sown grain on the station survived the winter. All data secured, therefore, is on spring sown varieties.

Twenty-eight varieties were tested under field conditions. In addition, over 100 other varieties were tested in the cereal nursery. The five best varieties were Early Baart, Wash. No. 618 with a yield of 13.8 bushels per acre; Karun No. 1333, 13.6 bushels; Bobs No. 1331, 13.1 bushels; Koola No. 1332, 12.4 bushels; Bluestem No. 501, 8.9 bushels.

Of the varieties tested, Early Baart is the leader. This variety of recent introduction now is widely grown in the drier sections of the state, being popular both from the growers' and the millers' standpoint.

The result of one year's test on date, rate, and depth of seeding spring wheat, is too inconclusive for report. However, in general, the early date, the heavier rates and a depth at least sufficient to prevent drying out of seed gave the best returns. One great advantage of the heavier rates lay in the more complete control of weeds.

Of the other cereals under test, the best spring rye gave an acre yield of 10.5 bushels, spring barley 16.2 bushels, and spring oats 19.5 bushels. Millets were seeded at two different dates with very indifferent results.

Forage.

Results with forage crops were not particularly encouraging. Alfalfa and sweet clover were so light in yield as to offer very little encouragement. Corn returned 7.1 bushels of grain, and 1500 pounds of stover per acre; broom corn 4000 pounds of stover per acre, and Russian sunflower also 4000 pounds per acre. Of all forage crops tried, field peas seem most promising.

The best varieties of field peas grown in 1917 and their yields were as follows: Bangalia, S. P. I. 8.9 bushels per acre; O'Rourke S. P. I. 7.3 bushels; Amraoti S. P. I. 6.9 bushels; Lima, S. P. I. ...7 bushels; Carleton, S. P. I. 6.6 bushels; Canadian S P. I. 6.6 bushels.

Peas may offer possibilities where they can be harvested by stock, but for grain alone the crop can not compete with wheat.

Additional work in winter cereals, tillage problems, soil fertility and rotations are also under way.

WATERVILLE BRANCH EXPERIMENT STATION

Intended primarily as a forage experiment station, work on the Waterville Station combines cereal production with forage cropping.

The best yielding winter wheats were as follows: Turkey Red No. — 32.5 bushels per acre; Turkey Red No. 326, 30.4 bushels; Triplet No. 597, 29.9 bushels; Turkey Bluestem No. 540, 27.3 bushels; Hybrid No. 128, 36.2 bushels.

The best yielding spring wheat varieties were as follows: Bluestem, Wash. No. 362, 28.7 bushels per acre; Early Baart, Wash. No. 618, 26.5 bushels; Chul x Bluestem, Wash. No. 622, 25.4 bushels; White Elliott, Wash. No. 1351, 22.6 bushels.

Field peas were also grown on the Waterville Station. The best yielding varieties were as follows: Kaiser S. P. I. No. 17006, 16.9 bushels per acre; Lima S. P. I. No. 23850, 15.4 bushels per acre; Amraoti S. P. I. No. 21709, 14.2 bushels; Bangalia S. P. I. No. 21288, 13.1 bushels; Grey Winter S. P. I. No. 16436, 13 bushels.

was therefore appointed including the Irrigation Engineer and the Assistant Soil Physicist of the Washington Experiment Station and the Irrigation Engineer of the U. S. Reclamation Service for Yakima Valley and a representative from the U. S. Department of Agriculture. Several available sites were considered and a site finally selected four miles northeast of Prosser above the Sunnyside Canal, as indicated in Fig. 8.

The Northern Pacific Railway Co. donated tract No. 1 and gave an option on tract No. 2 for \$30 per acre on condition that \$2000 be spent on improvements within one year, the option to be taken up within 30 days after the close of the sixteenth session of the Legislature. These two tracts were held under contract by the Hon. E. F. Benson, Commissioner of Agriculture, and the payments which he had made the railway company on the two contracts were accepted as total consideration for the 80-acre tract deeded to the state.

F. M. Rothrock has also granted a favorable option on tract No. 3. The soil of the entire tract of 207.98 acres varies from a light, sandy loam to a heavy, sandy loam and is well suited to the purposes of experimentation. Since this tract lies above the old ditch and is to be watered from a pipe line, there is practically no danger of seepage. The tract offers all slopes.

The citizens of Prosser donated \$3000 for the initial development of the tract and the work of clearing, plowing and leveling is in progress.

OFFICE OF FARM MARKETS

The fifteenth Legislature passed an act creating the "Office of Director of Farm Markets" with an appropriation of \$15,000 for the biennium, and authorized the Director of the Experiment Station to nominate the Director of Farm Markets and requisition the expenditure of the appropriation. The law became effective June 8, 1917, and active work began by the appointment of Asher Hobson as Director, with headquarters at Pullman. The Bureau of Markets of the United States Department of Agriculture has contributed \$1143.55 and the Extension Service of the State College \$1500.00 for co-operative work in marketing.

The office has maintained an assistant and a clerk for full time and has secured considerable aid through the hearty co-operation of the State Department of Agriculture.

The following is a brief summary of the activities of this office.

1. Organized 15 co-operative marketing associations.
2. Investigated and rendered a decision on 10 complaints of shippers of farm produce.
3. Conducted Food Survey (Federal Bureau of Markets) city of Walla Walla.
4. Addressed 196 previously advertised public meetings.
5. Participated in 192 marketing conferences with individuals and committees, exclusive of office conferences.
6. Analyzed business activities of the Washington Co-operative Egg and Poultry Association.
7. Compiled classified mailing list of growers of the state.
8. Compiled classified list of wholesale dealers of Washington farm products of Pacific Northwest.
9. Compiled classified list of farmers' business organizations of the state.
10. Issued Monthly Cold Storage Reports for state since November, 1917.
11. Published two bulletins.
12. Issued 19 circulars.
13. Contributed 16 special articles on marketing subjects to the agricultural press.
14. Conducted extensive research work on co-operative and cold storage laws in the United States.
15. Made detailed study of Public Markets in the state of Washington.
16. Issued 75 certificates of inspection.
17. Used 87,460 franked envelopes and 11,000 franked cards.

PUBLICATIONS

The following publications were prepared by members of the Experiment Station staff and published during the year:

General Bulletins.

147. Factors Influencing Water Requirements of Plants, by C. C. Thom and H. F. Holts.
148. Evaporation of Fruit and Vegetables, by J. S. Caldwell.
149. Preparation and Use of Pure Cultures for Legume Inoculation, by C. A. Magoon and B. S. Dana.
150. Studies on the Morphology of Wheat, by G. H. Jensen.

Popular Bulletins.

113. Home Preparation of Breakfast Foods and Flour from Whole Grain, by Geo. A. Olson.
113. Potatoes (poster) Some Potato Production Requisites, by R. J. Barnett, F. D. Heald, and A. L. Melander.
114. Two Methods of Preserving Eggs, by Geo. A. Olson.

Newspaper Bulletins.

244. Silage for Horses, Sheep, Cattle and Swine, by Wm. Hislop.
245. Separate the Ram Lambs from the Ewe Lambs, by Wm. Hislop.
246. Statement of Situation Relating to the Increase of the 1918 Wheat and Rye Crop, by Geo. Severance.
247. Planting a War Wheat Crop, by E. G. Schafer.
248. Increasing Wheat Production Through Better Tillage Methods in Regions of Light Rainfall (less than 18 in.), by A. M. Richardson.
250. Sprouted Oats for Poultry, by Mrs. H. D. Whitaker.

The following Extension publications were prepared by members of the Experiment Station staff:

Bulletins.

29. The Bulk Handling of Grain on Washington Farms, by Asher Hobson.
30. Directory of Breeders of Pure-Bred Livestock in Washington. Compiled by Wm. Hislop.
35. Spraying Formulas for Garden Insects, by A. L. Melander.
36. State Plan for Increasing Food Production (for 1918), by Geo. Severance.
39. Spraying Formulas for Orchard Insects, by A. L. Melander.
41. Spraying Practices for Fruit Diseases, by F. D. Heald.
44. Selection and Care of the Dairy Herd Sire, by E. G. Woodward.
45. Dairy Feeding Chart, by E. G. Woodward and K. B. Musser.
46. Prevention of and Protection from Smut Dust Explosions and Fire in Grain Separators, by E. G. Thornton.

Circular.

4. You Can Control Stinking Smut of Wheat, by F. D. Heald.

Entomology Circulars by A. L. Melander.

1. Treatment for Insects Infesting Stored Grain, Etc.
2. Currant and Gooseberry Maggots.
3. Bed Bugs.
4. Codling Moth Spraying.
5. Bee Culture Suggestions.
6. Ants.
7. Cutworms.

Botany Circular.

2. Inoculation of Legumes, by T. J. Murray.

FINANCIAL STATEMENT

Washington Agricultural Experiment Station in account with The United States Appropriations, 1917-1918

Dr.		Hatch	Adams
Receipts from the Treasurer of the United States, as per appropriations for fiscal year ended June 30, 1918, under acts of Congress approved March 2, 1887 (Hatch Fund) and March 16, 1906 (Adams Fund)			
		\$15,000.00	\$15,000.00
Cr.	Abstract		
Salaries	1	\$ 8,648.17	\$ 9,772.06
Labor	2	2,755.47	2,154.33
Publications	3	617.54	.....
Postage and stationery	4	451.14	25.23
Freight and express	5	146.89	53.89
Heat, light, water, and power	6	32.56	11.00
Chemicals and laboratory supplies....	7	25.00	665.55
Seeds, plants, and sundry supplies....	8	797.58	33.82
Fertilizers	9	74.86	24.05
Feeding stuffs	10	35.75	1,514.65
Library	11	11.65	.....
Tools, machinery, and appliances....	12	141.82	116.39
Furniture and fixtures	13	378.74	45.71
Scientific apparatus and specimens....	14	189.36	255.81
Live stock	15	.....	50.00
Traveling expenses	16	673.47	277.51
Contingent expenses	17	20.00	.....
Buildings and land	18	.....	.....
Total		\$15,000.00	\$15,000.00

FINANCIAL STATEMENT

State Funds Expended on Main Station and All Branch Stations, Including the Western Washington Station
April 1, 1917, to March 31, 1918

	State Appropriation	Contri- butions	Sales	Total
Salaries	\$19,059.12	\$ 65.00	\$ 3,326.65	\$22,450.77
Labor	10,717.31	....	2,771.08	13,488.39
Publications	3,060.72	....	2,614.17	5,674.89
Postage and stationery..	1,174.91	....	859.11	2,034.02
Freight and express	781.34	....	181.14	962.48
Heat, light, water, and power	586.90	....	206.69	793.59
Chemical and laboratory supplies	221.13	....	431.23	652.36
Seeds, plants and sundry supplies	2,732.05	20.12	1,312.68	4,064.85
Fertilizers	57.90	....	193.27	251.17
Feeding stuffs	5,760.45	....	1,372.21	7,132.66
Library	262.39	....	13.50	275.89
Tools, Mach'y and appli- ances	2,279.44	2.25	336.63	2,618.32
Furniture and fixtures..	689.45	....	96.69	786.14
Sci. apparatus and speci- mens	782.03	....	254.95	1,036.98
Livestock	250.00	....	.....	250.00
Traveling expenses	2,161.97	52.93	782.46	2,997.36
Buildings	7,599.11	....	1,347.00	8,946.11
	<u>\$58,176.22</u>	<u>\$140.30</u>	<u>\$16,099.45</u>	<u>\$74,415.98</u>
March 31, 1918, balances .....	.....	63.57	5,338.89	5,402.46
	<u>\$58,176.22</u>	<u>\$203.87</u>	<u>\$21,438.35</u>	<u>\$79,818.44</u>
April 1, 1917 balance on hand .....	.....	\$203.87	\$ 2,153.77	\$ 2,357.64
Receipts	\$58,176.22	....	19,284.58	77,460.80
	<u>\$58,176.22</u>	<u>\$203.87</u>	<u>\$21,438.35</u>	<u>\$79,818.44</u>

STATE COLLEGE OF WASHINGTON
Agricultural Experiment Station
PULLMAN, WASHINGTON

DIRECTOR'S OFFICE

Twenty-seventh Annual Report
For the Year Ending June 30, 1917

BULLETIN No. 152
January, 1918

All Bulletins of this Station sent free to citizens of the State on
application to Director

BOARD OF CONTROL

Wm. M. Pease, President	Seattle, Wash.
E. O. Holland (President of the College)	
Secretary ex officio.....	Pullman, Wash.
E. T. Comas	Spokane, Wash.
W. A. Ritz	Walla Walla, Wash.
R. C. McCroskey	Garfield, Wash.
A. D. Dunn	Wapato, Wash.

EXPERIMENT STATION STAFF

*Ira D. Cardiff, Ph. D.	Director and Botanist
Geo. Severance, B. S.	Acting Director and Agriculturist
O. L. Waller, Ph. M.	Irrigation Engineer
A. L. Melander, Sc. D.	Entomologist
O. M. Morris, M. S.	Horticulturist
A. B. Nystrom, M. S.	Dairy Husbandman
Geo. A. Olson, M. S.	Chemist
W. T. Shaw, M. S.	Zoologist
E. G. Schafer, M. S.	Agronomist
Wm. Hislop, M. S.	Animal Husbandman
F. D. Heald, Ph. D.	Plant Pathologist
C. A. Magoon, A. B.	Bacteriologist
J. W. Kalkus, D. V. S.	Veterinarian
M. A. McCall, M. S.	Dry Land Specialist
J. S. Caldwell, Ph. D.	Plant Pathologist
M. A. Yothers, M. S.	Assistant Entomologist
Henry F. Holtz, M. S.	Acting Soil Physicist
E. F. Gaines, M. S.	Cerealist
C. B. Sprague, B. S.	Assitant in Horticulture
H. M. Woolman	Assistant Plant Pathologist
F. W. Allen, M. S.	Assistant Horticulturist
M. B. Boissevain, B. S.	Assistant in Farm Crops
C. H. Hunt, M. A.	Assistant Chemist
O. E. Barbee, B. S.	Assistant in Farm Crops
Bliss Dana, M. S.	Assistant Bacteriologist

*Resigned April 30, 1917.

TWENTY-SEVENTH ANNUAL REPORT* **WASHINGTON AGRICULTURAL EXPERIMENT STATION**

CHANGES IN STAFF

Dr. Ira D. Cardiff resigned as Director of the Experiment Station April 30th, 1917, and the vacancy was filled temporarily by the appointment of George Severance, Head of the Department of Agriculture, as Acting Director. An advisory staff was appointed, consisting of Dr. F. D. Heald, Pathologist; O. L. Waller, Irrigation Engineer; George A. Olson, Chemist; Dr. J. W. Kalkus, Veterinarian, and Dr. A. L. Melander, Entomologist.

O. E. Barbee, class of 1916, Washington State College, was appointed Assistant in Farm Crops, April 1st, 1917.

C. A. Thompson was appointed Assistant in Soils on the Adams Branch Experiment Station, April 1st, 1917.

Mr. Claude B. Sprague, Assistant Horticulturist, resigned April 20, 1917, to accept the appointment of County Agent, Kitsap County. The vacancy was not filled.

M. B. Boissevain, Assistant in Farm Crops, stationed at Waterville, resigned May 17th, 1917, to accept an appointment as County Agent in Wyoming. He was employed jointly by the Waterville Board of Education and the Washington State College, devoting one-half time to each service. The arrangement was discontinued after Mr. Boissevain's resignation. Superintendent M. A. McCall of the Adams Branch Station continued the work with non-salaried labor after the resignation of Mr. Boissevain.

IMPORTANT ADDITIONS TO EQUIPMENT

During the year the College purchased 157.3 acres of typical Palouse land adjoining the present college farm. This land was assigned to the College of Agriculture with the under-

*Owing to the resignation of the Director so near the close of the fiscal year ending July 1, 1917, the Twenty-seventh Annual Report was not issued at the close of that fiscal year. In order to make the published record continuous the following brief summary of facts is issued as the Twenty-seventh Annual Report.

standing that the Experiment Station would be granted the use of such portions, from time to time, as might be needed for field experiments. The Board also purchased another tract of eight acres adjoining the present cereal nursery and assigned the same specifically to the Experiment Station. No other unusual equipment was added to the main Experiment Station at Pullman during the year.

On the Dry Land Station at Lind, a machine shed, shop, bunk house, and hog houses were added to the building equipment that had been erected during the preceding fiscal year. A threshing outfit, including an engine, a binder operated with a gasoline engine, and a stock scale were added to the equipment. Two hundred forty rods of hog-tight fence were erected for the protection of the experimental work.

At the Waterville sub-station, an office, machine shed and 280 rods of hog-tight fence were constructed. A moderate equipment of farm tools was also added.

PROJECTS UNDER INVESTIGATION

The following is a complete list of approved projects under investigation.

Station No.	Name of Project	Source of Support
Agronomy 26	Variety testing of cereals...	Hatch and State
Agronomy 27	Increase and Distribution of Seed.....	State
Agronomy 28	Inheritance in Cereals.....	Adams and State
Agronomy 29	Forage Investigation.....	Hatch and State
Botany 30	Metabolism of Tubercle Bacilli	Adams and State
Botany 31	Wheat Smut.	Hatch, State and Special B.P.I.
Botany 33	Tomato Blight & Related Diseases...	Adams
Botany 34	Relation of ripening processes in prunes to drying processes.	Adams and State
Botany 35	Biochemical study of apple varieties...	State
Chemistry 26	Functions of sulphur as a plant food..	Adams
Chemistry 30	Progressive Development of Wheat Kernel	Adams
Chemistry 31	Relation of Composition of Wheat to Soil Types	Adams
Chemistry 32	Baking Qualities of Flour.....	Adams
Chemistry 33	Influence of Cultivation on the Nitro- gen Content & Yield of Wheat.....	Adams
Dairy 5	Abnormal Milk	Hatch
Dry Land 1	Dry Land Cereal Investigations.....	State
Dry Land 2	Dry Land Forage Investigations.....	State

Dry Land	3	Dry Land Tillage Investigations.....	State
Dry Land	4	Dry Land Permanent Fertility Investigations	State
Dry Land	5	Dry Land Tree Trials & Distribution..	State
Dry Land	6	Dry Land Post Treating Trials.....	State
Entomology	22	A Physiological Study of the Changes Produced by Endoparasites.....	Adams
Entomology	30	Progressive Immunity of Insects....	Adams
Entomology	31	Strawberry Root Weevil.....	Hatch
Horticulture	12	Orchard Pollination	Hatch
Horticulture	13	Mendels Law in Blackberry & Raspberry hybrids	Adams
Horticulture	17	Winter dessication of Fruit Trees...	Adams
Horticulture	18	Relation of Soil Moisture to Keeping Qualities of Apples.....	State and Hatch
Horticulture	21	Top Grafting of Fruit Trees.	State and Hatch
Horticulture	22	Orchard Cover Crops.....	State and Hatch
Horticulture	23	Renovation of Prune Orchards in Clark County	State and Hatch
Horticulture	24	Variety Test of Garden Vegetables	State and Hatch
Horticulture	28	Frost Injury to Tender Plants and Fruit Tree Blossoms.....	State and Hatch
Soils	4	Soil Moisture Studies	Adams
Veterinary	6	Goitre and associated conditions in Domestic Animals	Adams and State

No new projects were added during the fiscal year, though several miscellaneous lines of work have been attended to by different departments.

On account of the ravages of crickets in certain portions of the Big Bend Area, the Legislature appropriated \$2000 to be used by the State Experiment Station to combat the pest. This was not a regularly approved project of the Station but was conducted as emergency work by the Division of Entomology, and reported in Bulletin No. 137, "The Coulee Cricket."

Disastrous outbreaks of the blackhead fireworm in some of the best kept cranberry bogs of Pacific County called for emergency visits of the Entomologist. Although few remedial measures were experimented with, a survey of the situation was made, resulting in a recommendation that it be made a regular project of the Experiment Station.

Another emergency investigation was made in cooperation with the U. S. Department of Agriculture and the Engineering Department of the State College to determine the cause of and possible methods of controlling the various forms of

smut explosions and also the possibility of catching and destroying a large percentage of the smut at the threshing machine in an effort to reduce the amount of soil contamination. The results were reported in Extension Bulletin No. 46, "Prevention of and Protection from Smut and Dust Explosions and Fire in Grain Separators."

A considerable portion of the time of J. S. Caldwell, Plant Physiologist, was devoted to rendering assistance to several commercial concerns in planning fruit evaporators.

The Lind and the Waterville Branch Stations were both under the direction of M. A. McCall, Superintendent of the Lind Branch Station. Dry Land projects one to four as listed under the list of Station projects were carried on at both branch stations, while Dry Land projects five and six were conducted at Waterville only.

The Office of Cereal Investigations of the U. S. Bureau of Plant Industry contributed \$2500 toward cereal investigations at the Lind Station.

The Winthrop Station, in charge of Dr. J. W. Kalkus, was devoted entirely to further study on the Goitre disease problems.

PUBLICATIONS

General Bulletins

No.

- 133 A Soil Survey of the Proposed Palouse Irrigation Project, by H. F. Holtz.
- 134 Sheep Husbandry in the Pacific Northwest, by William Hislop and C. E. Howell.
- 135 Inheritance in Wheat, Oats and Barley, by E. F. Gaines.
- 136 The Twenty-sixth Annual Report, by the Director.
- 137 The Coulee Cricket, by A. L. Melander.
- 138 First Annual Report, Adams Branch Experiment Station, by M. A. McCall.
- 139 Microchemical Studies in the Progressive Development of the Wheat Plant, by Sophia E. Eckerson.
- 140 Field Pea Production, by E. G. Schafer and E. F. Gaines.
- 141 Barley in Washington, by E. G. Schafer and E. F. Gaines.
- 142 Gluten Formation in the Wheat Kernel, by Geo. A. Olson.
- 143 Dipterous Families Sepsidae, by A. L. Melander and Anthony Spuler.
- 144 Wheat and Flour Investigations, by Geo. A. Olson.
- 145 The Estimation of Sulphur in Plant Material and Soil, by Geo. A. Olson.

- 146 Factors Influencing the Water Requirements of Plants,
by C. C. Thorn and H. F. Holtz.
147 A New Method for the Preparation of Pectin, by J. S.
Caldwell.

Popular Bulletins

- 103 Canning without Sugar, by J. S. Caldwell.
104 Cost of Pumping for Irrigation, by O. L. Waller.
105 The Possibilities of Sugar Beet Culture, by Ira D. Cardiff.
106 Potato Growing in Washington, by O. M. Morris, F. D.
Heald and M. A. Yothers.
107 Winter Sprays, by A. L. Melander.
108 Tree Planting in Eastern Washington, by O. M. Morris.
109 Celery Culture, by F. W. Allen.
110 Cabbage and Cauliflower Culture, by C. B. Sprague.
111 Bean Culture, by A. L. Strausz.

FINANCIAL STATEMENT

State Funds Expended on Main Station and All Branch Stations,
Including the Western Washington Station
April 1, 1916, to March 31, 1917

	State Approp.	Contri- butions	Sales	Total
Salaries	\$13,524.54	\$	\$ 7,176.40	\$20,700.94
Labor	6,230.16	120.00	4,723.96	11,074.12
Publications	1,809.64	.....	3,200.54	5,010.18
Postage and Stationery	426.79	.....	373.69	800.48
Freight and Express	401.19	22.66	332.34	756.19
Heat, Light & Power	359.55	.....	312.94	672.49
Chemical Supplies	941.93	.....	505.95	1,447.88
Sundry, Seeds, Plants	983.16	42.55	994.83	2,020.54
Fertilizers	284.93	.....	191.34	476.27
Feeding Stuffs	3,570.33	.....	653.53	4,223.86
Library	61.41	.....	39.91	101.32
Tools, Mchry & Appliances	1,050.07	718.30	672.52	2,440.89
Furniture & Fixtures	160.82	.....	69.68	230.50
Scientific Apparatus	171.32	.....	200.41	371.73
Livestock	493.75	.....	69.75	563.50
Travel Expense	1,056.38	.....	480.46	1,536.84
Contingent Expense				
Buildings and Lands	2,438.73	1,814.84	2,050.37	6,303.94
	<u>\$33,964.70</u>	<u>\$2,718.35</u>	<u>\$22,048.62</u>	<u>\$58,731.67</u>
Expenditures per above	\$33,964.70	\$2,718.35	\$22,048.62	\$58,731.67
March 31, 1917, balances.....	.....	203.87	2,153.77	2,357.64
	<u>\$33,964.70</u>	<u>\$2,922.22</u>	<u>\$24,202.39</u>	<u>\$61,089.31</u>

April 1, 1916,				
balance on hand.....		\$ 275.65	\$ 6,245.70	\$ 6,521.35
Receipts	33,964.70	2,646.57	17,956.69	54,567.96
	<u>\$33,964.70</u>	<u>\$2,922.22</u>	<u>\$24,202.39</u>	<u>\$61,089.31</u>

FINANCIAL STATEMENT
WASHINGTON AGRICULTURAL EXPERIMENT STATION
July 1, 1916, to June 30, 1917

	ADAMS	HATCH
Salaries	\$ 9,633.10	\$ 6,952.05
Labor	2,061.65	3,799.86
Publications		1,751.12
Postage and Stationery	3.93	399.14
Freight and Express	1,148.86	14.80
Heat, Light, Water & Power	6.25	90.65
Chemicals and Laboratory Supplies	78.23	36.94
Seeds, Plants and Sundry Supplies	81.48	572.44
Fertilizers		
Feeding Stuffs	1,512.49	
Library		119.05
Tools, Machinery and Appliances	37.85	187.84
Furniture and Fixtures		78.73
Scientific Apparatus and Specimens	15.79	62.73
Livestock	54.95	
Traveling Expenses	319.48	853.65
Contingent Expenses		20.00
Buildings and Lands	45.94	61.00
	<u>\$15,000.00</u>	<u>\$15,000.00</u>
Appropriation for the period		
July 1, 1916, to June 30, 1917	\$15,000.00	\$15,000.00

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STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIRECTOR'S OFFICE

**TWENTY-EIGHTH ANNUAL
REPORT**

For the Year Ending June 30, 1918

BULLETIN NO. 153

January, 1919

**All Bulletins of this Station sent free to citizens of the State on
Application to Director**

LETTER OF TRANSMITTAL

Pullman, Washington, January 18, 1919.
Honorable Ernest Lister, Governor,
Olympia, Washington.

Sir:

I have the honor to submit herewith the Twenty-eighth Annual Report of the State Agricultural Experiment Station, covering the work of this Station and Sub-Stations for the year ending June 30, 1918.

Very respectfully,

GEO. SEVERANCE,
Acting Director.

Board of Regents

Wm. Pease, President	Seattle
E. O. Holland (President of the college) Secretary ex-officio, Pullman	
W. A. Ritz	Walla Walla
A. D. Dunn	Wapato
R. C. McCroskey	Garfield
E. T. Coman, President since April, 1918.....	Spokane

Experiment Station Staff

Geo. Severance, B. S.	Acting Director and Agriculturist
O. L. Waller, Ph. M.	Irrigation Engineer
A. L. Melander, Sc. D.	Entomologist
O. M. Morris, M. S.	Horticulturist
Geo. A. Olson, M. S.	Chemist
W. T. Shaw, M. S.	Zoologist
E. G. Schafer, M. S.	Agronomist
Wm. Hislop, M. S.	Animal Husbandman
F. D. Heald, Ph. D.	Plant Pathologist
J. W. Kalkus, D. V. S.	Veterinarian
M. A. McCall, M. S.	Dry Land Specialist
F. J. Sievers, B. S.	Soil Physicist
E. G. Woodward, M. S.	Dairy Husbandman
T. J. Murray, M. S.	Bacteriologist
F. L. Pickett, Ph. D.	Botanist
E. F. Gaines, M. S.	Cerealist
Henry F. Holtz, M. S.	Assistant Soil Physicist
C. H. Hunt, M. A.	Assistant Chemist
O. E. Barbee, B. S.	Assistant in Crops
Anthony Spuler, B. S.	Assistant Entomologist
Bliss Dana, M. S.	Assistant Plant Pathologist
R. P. Bledsoe, M. S.	Supt. Waterville Substation
H. N. Coleman, B. S.	Superintendent of Advanced Registry Testing
E. S. Robertson, M. S.	Assistant Horticulturist

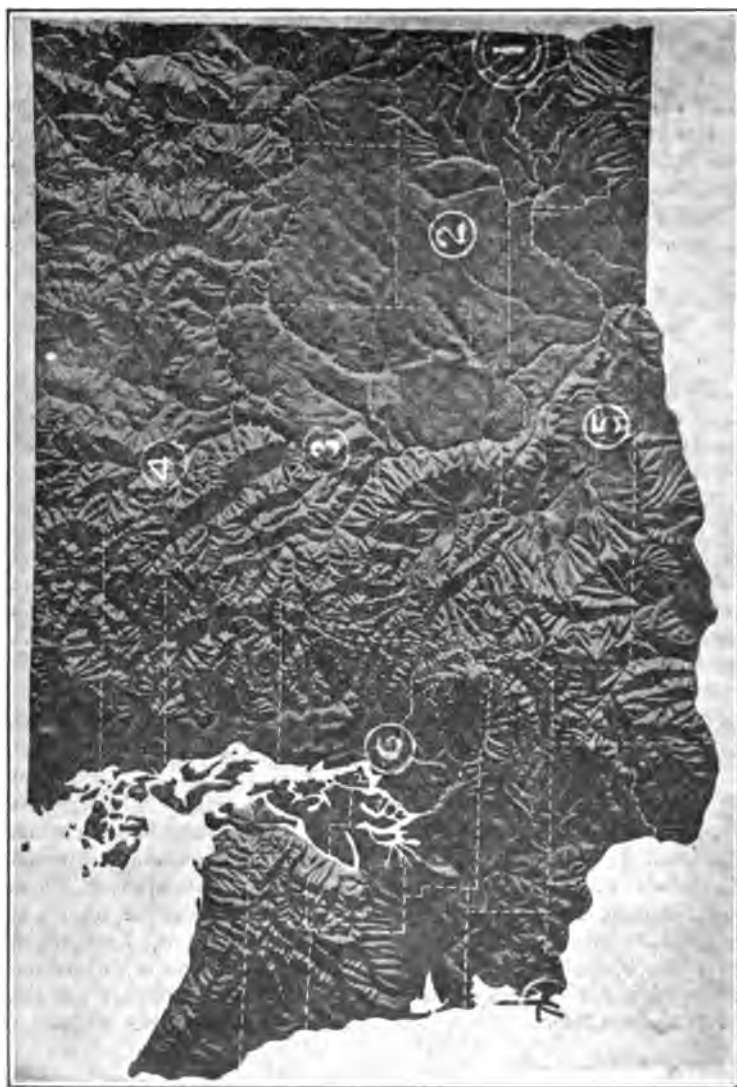


Fig. 1—Map of Washington, showing location of Agricultural Experiment Stations.

MAP OF WASHINGTON, SHOWING LOCATION OF AGRICULTURAL EXPERIMENT STATIONS

1. The main experiment station is located at Pullman, the seat of the State College, where the rainfall averages approximately 22 inches per annum. A farm of over 500 acres and the principal scientific laboratories are maintained here. Work on the more fundamental problems or those that require the use of laboratories and expensive equipment is carried on principally at Pullman.

2. The Adams Branch Station at Lind consists of 320 acres of typical soil and is devoted entirely to problems pertaining to the dry belt of Washington. The rainfall at Lind averages about 10 inches per annum.

3. The Waterville Branch Station consists of 220 acres of leased land and is devoted primarily to a study of forage problems and to an effort to develop a more diversified and permanent system of agriculture under the rainfall conditions prevailing in that region, which averages about 13.5 inches per annum.

4. The Winthrop Station consists of a five-acre tract with stock sheds and yards and is devoted exclusively to a study of the goitre disease of animals.

5. The Prosser Irrigation Station consists of 205 acres of unimproved land selected under authority of the 15th legislature as a site for an experiment station to study the many problems that are confronting the irrigation farmers. An option has been secured on this tract and it is being cleared and leveled with funds donated by the Prosser people. Its final purchase and further development depend upon an appropriation from the 16th legislature for that purpose. The importance of developing this experiment station may be appreciated from the fact that Yakima and Wenatchee Valleys alone produced in 1918 over \$30,000,000 worth of irrigated products and that Yakima Valley lost from the codling moth alone over \$2,000,000. Its importance may be further appreciated from the fact that the present irrigated area in Washington is only a small percentage of what may ultimately be brought under irrigation.

6. The Western Washington Experiment Station is located at Puyallup, where the average rainfall is about 45 inches per annum. It consists of 90 acres of typical valley soil and hill land and is devoted to a study of Western Washington problems.

7. The cranberry station is located at Ilwaco and is devoted entirely to a study of insects injurious to cranberries, and is maintained co-operatively by the State College of Washington and the Bureau of Entomology of the U. S. D. A.

TWENTY-EIGHTH ANNUAL REPORT

WASHINGTON AGRICULTURAL EXPERIMENT STATION

The work of the Experiment Station was very materially affected during the past year by the war. It was so shaped as to meet the great need for maximum production, and much of the time of several experiment station men was devoted to those activities which best would further the program of the state and nation.

The U. S. Department of Agriculture assigned five entomologists to the Extension Department of the State College and Dr. A. L. Melander, Entomologist of the Experiment Station, was appointed project leader for Washington. The government also assigned four wheat smut specialists to the Extension Department of the State College and Dr. F. D. Heald, Pathologist of the Experiment Station, was appointed project leader for Washington. Professor O. M. Morris, Horticulturist of the Experiment Station, was appointed project leader in horticulture.

Professor E. G. Woodward, Dairy Husbandman, Professor F. J. Sievers, Soil Physicist, and Professor E. G. Schafer, Agronomist of the Experiment Station, each devoted considerable time to the work for maximum production. Various members of the staff also devoted more time than usual to preparing press material. A series of articles prepared by members of the staff was run in nine of the leading papers of the state for several months.

Dr. J. S. Caldwell, By-Products Specialist, devoted the greater part of his time during the fall of 1917 as adviser to several companies in the Northwest, who were erecting by-product factories. One month during the fall was given to the Bureau of Chemistry, U. S. Department of Agriculture, upon request.

late in December, he resigned to enter the employ of the Bureau of Plant Industry.

The time of these men was diverted to extension work, as it was felt that they thus could render greater immediate service in the war emergency.

The unusual demand for trained men resulted in some resignations, several of which were for the purpose of engaging in United States government emergency service. Both on account of the shortage of help and of the unusual cost of both labor and supplies, it was necessary to suspend temporarily several projects. No funds were assigned to the Divisions of Animal Husbandry, Dairy Husbandry, and Irrigation Engineering, it being felt that the specialists in these divisions could render greater immediate service through extension work.

Changes in Staff.

Dr. J. S. Caldwell, By-Products Specialist; Wm. Hislop, Animal Husbandman; M. A. Magoon, Bacteriologist; A. B. Nyström, Dairy Husbandman; C. A. Thompson, Assistant in Soils, Adams Branch Station; F. W. Allen, Assistant Horticulturist; H. M. Woolman, Assistant Plant Pathologist, and M. A. Yothers, Assistant Entomologist, resigned during the year.

The following appointments were made: E. G. Woodward, Dairy Husbandman; T. J. Murray, Bacteriologist; R. P. Bledsoe, Superintendent Waterville Sub-Station; Anthony Spuler, Assistant Entomologist, and H. N. Colman, Superintendent of Advanced Registry Testing. Bliss Dana was transferred from Assistant in Bacteriology to Assistant in Plant Pathology.

Reports by Divisions

DIVISION OF ANIMAL HUSBANDRY

No funds were appropriated to this Division for the fiscal year just closed, but the following investigations were made through the aid of college students and the use of the college live stock.

Feeding Value of Feed Peas vs. Barley.

An experiment was conducted to determine the fattening value of field peas as compared with barley when supplemented with tankage and oil meal. Fifty-one shoats, bred by the State College of Washington, consisting of pure bred Duroc Jerseys, Poland China-Berkshire cross breds, and Poland China-Duroc Jersey cross breds were used. For comparison they were divided into four lots. The feeds used included cracked or split peas, common, beardless rolled barley, shorts, oil meal and tankage guaranteed to contain 60 per cent protein. The experiment continued 49 days during January and February, with the weather quite unfavorable for good feeding results.

The following table shows the rations fed, total grain consumed and total gains for each lot.

	Lot 1	Lot 2	Lot 3	Lot 4
	60% Barley 30% Shorts 10% O. M.	60% Peas 30% Shorts 10% Tankage	60% Peas 30% Shorts 10% O. M.	60% Barley 30% Shorts 10% Tankage
No. of hogs on test....	13	12	13	13
Initial weight per head (average)	99.77	107.33	107.84	100.69
Final (average)	160.38	184.75	162.77	169.62
GAIN IN LBS., TOTAL	788.00	929.00	714.00	896.00
GRAIN, LBS., TOTAL	3765.00	3818.00	3100.00	3820.00
Grain per lb. gain	4.77	4.10	4.34	4.26
Shrinkage in shipment to Stanton Packing Co., Spokane, per cent	11.66	16.75	18.50	16.63
Dressing per cent by lots	82.00	82.70	80.10	83.00

The feeds were assigned the following values per ton: peas, \$40.00; rolled barley, \$40.00; shorts, \$27.00; oil meal, \$50.00; tankage, \$50.00.

A study of the above figures indicates the following:

1. That peas and protein supplement such as tankage and linseed oil meal are superior to barley and a protein supplement, such as tankage and linseed oil meal.

2. That tankage, which is an animal protein, is superior to linseed oil meal, which is a vegetable protein, when fed to fattening hogs, in conjunction with barley or peas.

3. That a ration of peas, shorts and tankage ranks first; barley, shorts and tankage ranks second; peas, shorts and oil meal ranks third; and barley, shorts and oil meal ranks fourth in net profit and in the amount of grain required per hundred pounds of gain.

Relation of Breed and Age of Service to Prolificacy.

A study of the records of the college herd of swine of 1908 to 1916 was made to determine the relation of breed and age to prolificacy. The following is a summary of the facts obtained:

In Duroc Jersey swine, the total number of pigs under consideration was 400 and the average litter for that period was 7.143 pigs.

In Poland China swine, 479 pigs were studied and the average litter was 7.15 pigs.

In Berkshire swine, the number of pigs studied was 331, and the average litter was 6.245 pigs.

In Tamworth swine the number of pigs studied was 127 and the average litter was 7.94 pigs.

The above figures on the relative prolificacy of breeds at the State College of Washington indicates Tamworth, first; Poland China, second; Duroc Jersey, third; and Berkshire, fourth.

In this work it is also brought out that the size of the litter increases as the age of the sow increases, up to four years. Sixteen yearling sows produced an average litter of 6.12

pigs; 17 two-year-old sows, an average litter of 7.7 pigs; 10 three-year-old sows, an average litter of 7.8 pigs; and four four-year-old sows an average litter of 7.9 pigs.

DIVISION OF BOTANY

The Division of Botany has been of direct service to the farmers of Washington and adjoining states through the identification of weeds and native plants and the testing of seeds. The inquiries along these lines have increased to more than a thousand a year.

Investigations of weed distribution in the state, records of the introduction or spread of new weed pests and plans for the practical study of means of eradicating weeds, have been pursued. Study of weed habits and control will be greatly aided through the use of an area on the College Farm set aside this year as a weed garden. A special study of the wild oats situation in Washington has brought in valuable information concerning the limiting of this weed's range by rainfall and concerning the varieties found in the state.

In conjunction with the Division of Farm Crops there is in preparation the first of a series of bulletins containing descriptions, distribution data and suggestions for the control of the serious weed pests of the Northwest.

DIVISION OF BACTERIOLOGY

Legume Culture Work.

In co-operation with the Division of Farm Crops, inoculation material for legumes to the amount of 11,693 acres, has been furnished to farmers. The work has paid for itself. Last year these cultures were sent out in sand. A little complaint was heard because of the damaging effect of the sand on the drills. This year, as a result of some laboratory investigations by C. A. Magoon, cultures have been sent out in bottles on agar media. The results of the sand as an inoculum have met with marked success in the field. The field results from the use of the new method of using agar media as an inoculum have not yet been obtained. Methods are still

in an experimental stage and considerable work must be done in order to place the work on a firm scientific basis. A full time assistant should be employed to devote his entire time to practical and investigational legume work. The inoculation of the soil of Eastern Washington is a work well worth while.

Bovine Tubercular Bacillus.

This work was outlined and started by C. A. Magoon. A bulletin, "Isolation and Cultivation of Bacterium Tuberculosis on a Synthetic Medium," was published in 1918. Because of the pressure of the legume culture work, no work was done on the project last year. Work has been started and is now under way with a view to completing this project.

The Effect of Straw on the Soil.

It has been observed that the addition of straw to the soils of Eastern Washington causes a decrease in the following crop yield. The above named project was taken up in co-operation with the Department of Soils with the view to determine the cause of this decrease in yield and to devise, if possible, some method of returning humus to the soil in the form of straw without ill effects.

Enough experimental data has not yet been obtained to draw conclusions. However, from the results thus far secured it seems that the addition of straw between one-tenth per cent and seven-tenths per cent stimulates nitrification, or the ability of the soil organisms to form nitrates. Between seven-tenths per cent and two per cent the straw inhibits nitrification and above two per cent, the addition of straw actually causes a decrease in the nitrate content of the soil. The nitrogen in the last case, however, is only temporarily lost to the plant as a food. It is transformed to protein nitrogen.

Miscellaneous Analyses.

Fifty-eight samples of water have been analyzed for the citizens of the state east of the Cascades. Five examinations have been made for the presence of the tubercular bacillus in

sputum; one for the presence of the tubercular bacillus in faeces; one for the presence of the tubercular bacillus in milk; 15 examinations of diphtheria swabs; five urine analyses and seven gonococcus examinations have been made.

DIVISION OF CHEMISTRY

The station chemist is also state chemist by virtue of his office and is, therefore, obliged to supervise a great deal of analytical work for the State Department of Agriculture in the control of foods, feeds, fertilizers. Some of this work has been particularly pressing, owing to war conditions and has, therefore, demanded more than usual attention. Furthermore, the unusual demand for chemists during the war has forced the station chemist to run very short handed, making it impossible to do the usual amount of station work. Work was temporarily suspended on "the function of sulphur as plant food." "Co-operative study of methods of analyses with the Association of Official Agricultural Chemists," and "the relation of soil types to composition of wheat."

The following is a summary of results obtained with the projects studied:

The Baking Qualities of Flour.

This project has been studied under three main heads: (a) influence of electrolytes on baking quality, (b) the use of substitutes for wheat flour on baking quality, and (c) a study of the physical properties of gluten and its possible bearing on the baking quality of flour.

(a) There are a number of preparations sold on the market which are used in combination with other materials for the purpose of improving the quality of the dough and ultimately with the object of improving the loaf of bread. Among such preparations is one known as Arkady Yeast Food, which patented preparation consists of calcium sulphate, ammonium chloride, potassium bromate, and a flour filler. This preparation, when used in conjunction with the other necessary ingredients, is claimed to save yeast and flour and increase the volume of the loaf of bread.

Investigations indicate that the Arkady Yeast Food shows beneficial effects with some flours, while with others no results were observed. In no case were all of the benefits claimed from the use of such materials observed in any one flour.

(b) Flour substitutes were studied with flours made from oats, barley, rice, yellow and white corn, apples, alfalfa, soy beans, but more especially with field peas and soy bean cake used in various combinations with wheat flour. The field peas used were of the Bangalia and Amraoti varieties. The Bangalia possesses a bitter principle which we found to be present in the hull and is removed in the process of milling. The soy bean cake which we used is the kind that is used for feeding stock and contains from six to eight per cent of oil instead of 16 to 18 per cent of oil, which is present in the original grain.

The advantage in the use of materials such as pea flour and soy bean flour lies in the fact that these materials contain considerably more protein than is found in the common cereals. The peas contain 25 per cent of protein and the soy bean cake contains about 46 per cent of protein. Cottonseed flour is also high in protein but not as high as soy bean cake. With the use of these materials it was thought that a saving in the consumption of meat could be made and at the same time meet the body requirements for protein. Legume flours should also be valuable as a food for people suffering from diabetes, owing to their low starch content.

Many plans were devised and worked out with the view of increasing the volumes of the combination of flour breads. Experiments were conducted with varying amounts of electrolytes, sugar, different kinds of sugar, varying amounts of yeast and also with combinations of the cereals other than wheat flour. In some of the experiments gluten was added. It was found that the volume of the loaf could be held to a size obtained from the use of wheat flour alone if not more than 10 per cent of pea flour or other substitute cereal flour were used. With the use of 15 per cent of pea flour, the vol-

ume of the loaf decreased five per cent, and with 20 per cent of pea flour the volume decreased 10 per cent. In other words, the volume of the loaf was inversely proportional to the amount of substitute used over 10 per cent. The results for soy bean cake flour and all other cereal substitutes gave similar results.

The flavor of the pea flour bread is very good. The crumb of a greenish cast, which can not be regarded as objectionable. The soy bean cake flour does not taste as good as the pea flour bread and the color of the crumb is of a yellowish tint. Apple flour gives to the bread an acrid taste. The color of the apple flour crumb is of a brown hue, similar to that obtained in brown bread. The bread made from alfalfa flour tastes of weeds and the color of the loaf is objectionable. The results of these investigations are encouraging and justify further investigations to determine the extent to which substitutes may be used to advantage in peace times.

(c) Studies on physical properties of gluten indicate that the physical properties of the gluten of a given sample of flour are not entirely inherent, but are determined to a large extent by certain chemical composition which may be determined largely by environmental factors.

Influence of Cultivation on Nitrogen Content.

Winter varieties of wheat studied showed an average nitrogen content under cultivation of 2.86 per cent and without cultivation of 2.87. Spring varieties showed an average nitrogen content of 2.77 per cent with cultivation and 2.73 per cent without cultivation. These results would indicate that cultivation for this season gave practically no results in either direction. They may be due to the fact that the experiments were conducted on land that has been kept in a high state of cultivation for several years by the growing of peas every third year and by thorough tillage. In another field where the above varieties were grown in the ordinary way and without cultivation, the winter varieties averaged 2.47 per cent nitrogen and the spring varieties averaged 2.56 percent nitrogen.

This bears out former observations that the nitrogen content of wheat may be increased and the quality of wheat decidedly improved by keeping the soil in a high state of cultivation and well supplied with nitrogen through the growing of legumes.

Use of Gypsum and Land Plaster.

Co-operative tests with land plaster have been conducted on a few farms around Pullman. Selected areas of treated and untreated alfalfa were measured and weighed on the H. H. Curtis farm and an increase of over 200 per cent was noted on the treated plot. Similar results were reported by other co-operators but unfortunately lack of labor made it impossible to measure and weigh accurately on the other farms.

This problem deserves further study, not only to determine the possibilities of increasing production by this means, but also to determine the ultimate effect upon the soil.

Studies on Pectin.

A method for recovering the pectin contained in fruit pomace has been devised that should prove of commercial importance. By this method, ammonium sulphate is substituted for the more expensive alcohol with the added advantage that the spent salt is valuable as a fertilizer.

There are several possibilities for the use of pectin besides that for the making of jelly, justifying more attention to the saving of this by-product. Cider and vinegar manufacturers could recover considerable pectin from the pulp that is thrown away after removing the cider.

Miscellaneous Analyses.

A large number of miscellaneous analyses have been made. Samples of feeding stuffs sent in by citizens were not analyzed, owing to the fact that the state law provides for an authorized inspector to sample commercial feed stuffs for official analyses. However, in a few cases where analyses were requested for good reasons, other than to determine the commercial status of the feed, such analyses have been made.

A number of analyses were made in cases of suspected poisoning. Numerous other routine analyses were made.

DIVISION OF DAIRY HUSBANDRY

No funds were assigned to this division for the past fiscal year, but the Station assumed responsibility for the Advanced Registry Testing in March, 1918.

Summary of Advanced Registry Testing for 1918 is as follows: Number of herds tested, 61; divided as follows: Holstein, 32; Jersey, 22; Guernsey, 4; Ayrshire, 3.

Number of different supervisors used, 35; averaging from 7 to 13 per month.

Tests conducted total 2523, as follows: 2-day tests, 2270; 7-day tests, 174; 14-day tests, 1; 21-day tests, 1; 30-day tests, 47; 60-day tests, 5; 90-day tests, 1; 100-day tests, 3; re-tests on high production, 21.

The number of tests conducted in 1918 is 81 per cent of the number conducted during 1917, which is very pleasing, considering the handicap of the war conditions and shortage of help.

Among the class leaders, nationally, the following Washington cows appear. The order of the records being name, number, milk production, average per cent, butterfat production, and rank.

Jerseys:—

Senior 3-year-olds:

Eminents Foxy Belle, 304982, 14920.6, 5.47, 816.65, 3rd.

Senior 4-year-olds:

Olympia's Fern, 252060, 16147.8, 5.81, 937.8, 1st.

Guernseys:—

Junior 2-year-olds:

Kulshan Hayes May Rose, 73318, 8261.20, 6.06, 500.45, 5th.

Ayrshires:—

The last Ayrshire Quarterly (1918) gives data on the following Washington cows:

Leaders in milk production:

Willowmoor Soncy Girl, 16707, 4.25, 709.60, Mature, 1st.

Willowmoor Etta 3d, 16621, 4.01, 666.06, Junior 2, 1st.

Leaders in fat production:

Lilly of Willowmoor, 22596, 4.23, 955.56, Mature, 1st.

Willowmoor Lily 5th, 14577, 4.55, 662.53, Junior 3, 1st.

Holsteins:—

The last "Blue Book," Vol. 29, gives the following Washington cows ranking first in their classes:

30-day records:

Von Heim Mary Hartog, 284404, 2054.9, 4.69, 46.383, Senior 2.

Von Heim Winnifred Colantha, 329334, 1925.4, 4.89, 94.164, Junior 2.

7-day records:

Von Heim Winnifred Colantha, 284404, 444.5, 5.33, 23.698, Junior 2.

365-day records:

Ormsby Segis Marie, 223321, 27025.7, 3.18, 859.63, Senior 3.

The Advanced Registry Testing is practically self supporting from the fees paid by the breeders for this work. From May 1, 1918, to January 1, 1919, nearly \$6000 has been paid out for the work from the fees received; the monthly average being from \$700 to \$750.

With the close of the war the future prospects are very encouraging as is indicated by the numerous letters of inquiry being received regarding the work. There are quite a number of breeders taking up official testing for the first time as well as many of the older breeders who temporarily discontinued official testing.

DIVISION OF FARM CROPS

In a report of the investigational work of the Division of Farm Crops, a single year's work is of little value by itself. The year's work therefore has been supplemented by adding data obtained in prior years in a number of cases. The experimental work being done is analyzed and interpreted so that farm practices may be benefited by it.

The work of variety testing which must continue to be an important part of the work as long as new varieties are being

introduced in the state, has been increased about 25 per cent. New introductions as well as new hybrids of exceptional promise, produced at the Experiment Station, are being compared with standard varieties in field tests. More extensive plans have been devised to distribute superior varieties of grains. Through the co-operation of the county agriculturists, their value is being checked up with other varieties in the various localities where superior grains are distributed.

Experiments are in progress which show definite possibilities of producing smut resisting varieties of wheat and oats by breeding. Definite information is being accumulated which throws considerable light upon the problem of what constitutes winter hardiness in wheat. Information is being gained on the comparative value of different crops for silage. Experiments are being conducted to determine methods of production by which clover and alfalfa seed may be profitably produced within the state. Crop rotation experiments are being started which should have a far reaching influence on the cropping system to be practiced in the future.

The division between the work of two years naturally comes with the harvest. As this report covers the work for the year ending June 30, 1918, it deals with the crop harvested during the summer and fall of 1917.

Variety Testing.

A summary of results to date indicate the following:

1. Hybrid 128, which was produced and distributed by the State College of Washington, is the best winter wheat under conditions that prevail at Pullman; Bluestem is the best spring wheat, except in the arid sections of the state, where Baart does better.

2. Banner oats, introduced direct from Scotland and distributed by the Experiment Station, is distinctly superior to all others in yield, in Eastern Washington. Abundance is a close competitor and has been distributed to some extent. Sixty Day is lowest in yield, both in 1917 and in the four-year average. White Bonanza ranks first for the Skagit Flats in Western Washington.

3. The coast barleys are the most satisfactory varieties to grow and will yield more pounds to the acre than any other grain crop. Winter barleys should not be recommended, as they are not winter hardy and on the average, the yield is 13 bushels less than spring barleys.

4. Bangalia is the best variety of peas in total yield, but on account of market discrimination and from the fact that Bluebell matures somewhat later, it may be more profitable where the seed is to be marketed or when planted with the later maturing varieties of oats for hay.

5. Mexican Red beans are by far the best variety for the Palouse country. Yakima Pinks are preferable in the warmer irrigated sections.

6. The best rate to seed corn varies with the season, ranging from two to five stalks per hill; three stalks being on the average the best during the years tested.

7. Chick peas, the sorghums and Soy beans are not to be recommended except in restricted districts of long season and high temperature.

8. Minnesota No. 2 rye is the best winter variety; Beardless is the best spring variety.

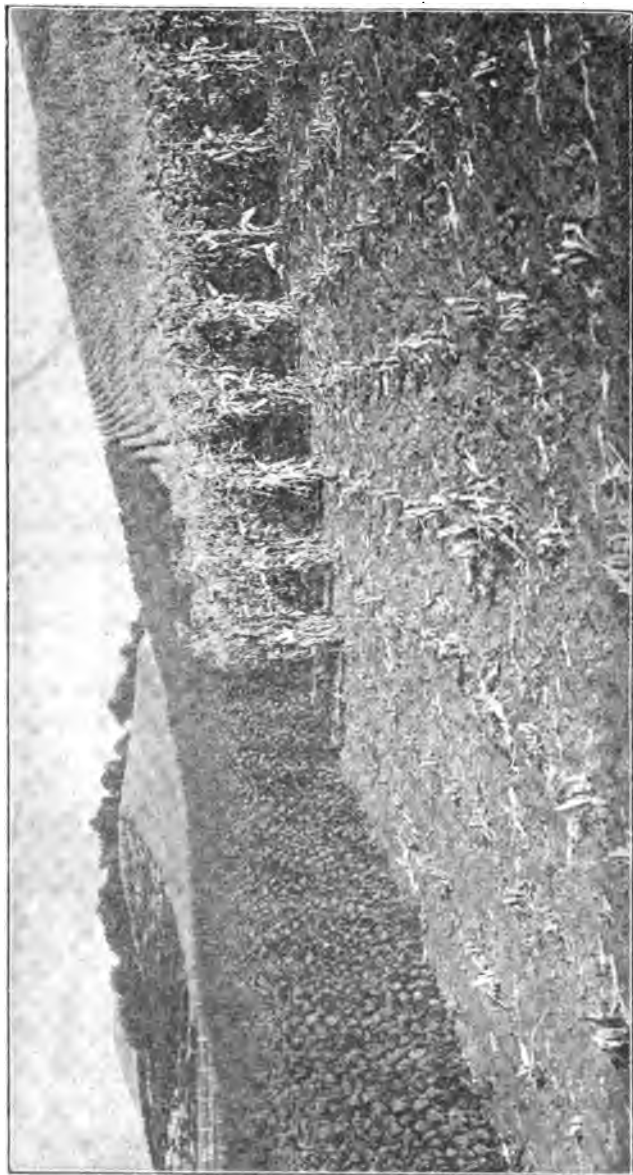
9. Minnesota No. 25 flax out-yields the best of the other four varieties tested by 45.7 per cent (two years average).

10. The date of seeding winter wheat experiment showed late August and early September seeding to give the highest yield in 1917. One season's results should not be accepted as conclusive.

11. The plots with various degrees of smutting were not conclusive in 1917, but a two-year average shows a decrease in yield in proportion to an increase in amount of smut produced.

Increase and Distribution of Seed.

More than 33 tons of pure seed, and bacteria culture prepared by the Division of Bacteriology sufficient for 11,693 acres of legumes, have been distributed throughout the state in 1167 different shipments during the year ending June 30, 1918. The standard maintained for seed sent out was kept



The Winter Hog Lot

Fig. 2—The Winter Hog Lot. On the left is a field of artichokes that produced 11.4 tons of silage per acre from the tops and 14.4 tons of tubers on the roots. The corn produced 71 bushels per acre. When the ground isn't frozen the hogs will dig and eat the artichoke tubers.

so high that more than 70 tons were discarded for feed or flour.

Inheritance Studies.

Definite information has been obtained on the inheritance of smut-resistance, winter habit, grain and glume color, sterility, beards and dwarfness of wheat. Considerable material has accumulated on the inheritance of various characteristics of wheat, oats, barley, corn, peas, rye, and forage plants which has not yet been compiled and interpreted.

Forage Investigations.

Turnips and rutabagas produce the largest tonnage per acre of the root crops. Winter wheat produced a larger tonnage of green forage for silage than any other single crop or combination in 1917.

Preliminary results indicates that the red clover seed can be profitably produced when proper spacing methods and proper time of cutting have been worked out. Work has been started to determine the possibilities of using a nurse crop in obtaining a stand of clover and alfalfa.

Cultivation and Rate of Seeding Wheat.

Wheat seeded in ordinary drill rows yields more than when the rows are spaced 12 to 18 inches apart. Cultivation is of material benefit to winter wheat, but decreases the yield of spring wheat.

Methods of Applying Manure to Wheat.

The average of 18 years tests with manure applied as top dressing on summer fallow wheat versus plowing under the same amount of manure for summer fallow show best results from top dressing.

Methods of Summer Fallowing.

The results of 18 years tests show best results from early plowed, well tilled summer fallow.

Crop Rotations.

Eighteen years tests comparing crop rotations including clover, straight wheat and summer fallow, cropping with

wheat every year with no fertilizer, and cropping with wheat every year with 10 tons of manure per acre applied annually indicate:

1. A quite marked and regular decline in yield under annual wheat cropping without manure with the yields at the beginning of the 18-year test bearing the usual relation to those on summer fallow.

2. That wheat seeded annually with an application of 10 tons of manure per acre yields as much now as at the beginning of the period and yields practically as much as the well tilled summer fallow plots, showing that summer fallowing is not necessary with the rainfall received at Pullman if the fertility of the soil can be properly maintained.

3. That in rotations that include clover and eliminate summer fallow, the yields of wheat are maintained nearly equal to the yields on well tilled summer fallow. Since the rotations used provide wheat half the time, the advantage of the rotation is apparent.

DIVISON OF HORTICULTURE

Orchard Pollination.

Tests were made of the self sterility of the Jonathan and Rome Beauty varieties of apples and of the influence of these on the setting of fruits by these trees when cross pollination was not permitted. Both varieties set a few fruits without cross pollination, when pollinated by the normal fall of pollen and distribution of pollen and by the work of bees. The fruits set on these trees contained very few seeds and a large proportion of seedless apples. The Jonathan apple produced on the tree which was inclosed by a tent and to which bees were admitted averaged 1.2 seeds per apple. Rome Beauty apples under the same conditions averaged one seed per apple. The Jonathan to which no cross pollination or insects were admitted during the blossoming period produced fruit which contained 1.9 seeds per apple. The Rome Beauty under similar conditions produced fruit that carried 4.8 seeds per apple. The Jonathan in the open orchard produced seven seeds per apple

and the Rome Beauty averaged 10 seeds per apple. No appreciable difference existed in the size or appearance of the fruits that were produced by self pollination and those produced in the open orchard.

Mendel's Law of Blackberry and Raspberry Hybrids.

The fruiting of a large number of blackberry and raspberry crosses developed the fact that the Evergreen Blackberry is the only variety which comes true to seed. The variation in the seedlings of the common varieties of blackberry and raspberries and their hybrids are existent in every part of the plant and fruit. The crosses within the specie will be eliminated from the work. No plants fruiting have shown indication of being worthy of consideration as a new variety for introduction into general use.

Winter Dessication of Fruit Trees.

The first year's work with trees grown in sand and given nutritive solutions to determine the influence of varying quantities of alkali and nitrates, has not given any indication that the cause of the trouble is a result of an unbalanced food supply in these particular food materials.

Relation of Soil Moisture to the Keeping Quality of Apples.

The work on this project was conducted along similar lines to the work of previous years. The results clearly indicate that so long as the moisture conditions of the soil are such as to produce normal fruit, the keeping quality of the fruit is not noticeably modified by that factor. The extremely large fruits have broken down in storage first and in most cases the fruit with an undersupply of color of the red varieties have broken down before those highly colored.

Orchard Cover Crops.

This work was continued along the lines reported in the last annual report. It is evident in the rainfall sections that late plowing under of the growing cover crop in the spring is the cause of unsatisfactory results in the use of such crops. Humus is developed at the expense of the fruit crop being pro-

duced and the indications are that only very limited value can be derived from cover crops in Eastern Washington in fruit producing orchards.

Renovation of Prune Orchards in Clarke County.

Work on this project consisted in starting fertilizer tests in five orchards in which nitrate of soda, ground blood and tankage and a mixture of nitrate of soda and ground blood and tankage were used. Results, although incomplete, indicate that the nitrate of soda is a very helpful fertilizer for the prune orchards of Clarke County.

Variety Tests of Garden Vegetables.

A study of the varieties of the potatoes grown in this state indicate that in Eastern Washington for early potatoes the Early Ohio and Early Rose are best. For the main crop the Burbank, Rural New Yorker, Gold Coin and American Wonder are very popular and profitable varieties. In Western Washington the Early Ohio and Early Rose and Irish Cobbler are the best early varieties. The Burbank, Pride of Multnomah and Rural New Yorker are the leading main crop varieties. In the irrigated sections the Netted Gem and Russet Burbank are the leading main crop varieties.

Frost Injury to Tender Plants and Fruit Tree Blossoms.

The work done on this project seems to indicate that resistance to frost injury is not correlated with the physical vigor of the plant, but in many cases seems to be inversely in proportion to the amount of new growth developed by the plant. Blossoms produced by the most vigorous plants are usually more easily killed than those produced by less vigorous plants. The cell tension existing in the plant at the time of a reduction of temperature to the danger point and the subsequent rise of temperature is probably the most influential factor determining the amount of injury done.

DIVISION OF IRRIGATION ENGINEERING

No funds were appropriated to the Division of Irrigation Engineering, the work of the Division being confined to personal aid in matters pertaining to irrigation engineering.

DIVISION OF PLANT PATHOLOGY

The work of the Division of Plant Pathology during the past year has resulted in marked progress on its three principal projects. The following are some of the more important results obtained:

Wheat Smut.

1. Normal grains from partially smutted heads do not transmit the disease.
2. Strong bluestone solution (1-1 formula) sprinkled on the seed very greatly reduced the infection from smut in the soil.
3. Early plantings (August) were practically free from smut, and gave good yields.
4. Replowing which had been suggested as a means of reducing smut increased rather than reduced the yield.
5. Smut loss is not accurately estimated by a head count.
6. Exhaust fans on threshing machines, if properly installed lessen the danger of explosions, improve the quality of the wheat and prevent much of the smut dust from passing out through the stacker.

Rhizoctonia Diseases.

1. Additional evidence has been obtained that tomato blight is caused by Rhizoctonia, and that the disease may be transmitted from the potato to the tomato.
2. The standard mercuric chloride treatment of seed tubers does not increase the yield of table stock, but should be used for the production of extra fancy or seed stock free from sclerotia.
3. Seed selection is of more value than seed treatment in the prevention of loss from Rhizoctonia.

Fire Blight.

Leaf invasions of *B. amylovorus* were produced by inoculation and a certain per cent led to twig blight by migration downward through the leaf petioles.

Powdery Scab.

Tests indicate that powdery scab on potatoes is comparatively harmless in Washington.

Potato Storage.

Investigations show that spindling sprouts of potatoes may result from poor conditions of storage.

Identification and Study of Miscellaneous Diseases.

This work has constituted the basis of the Plant Disease Survey which is carried on in co-operation with the Federal Plant Disease Survey. Specimens and inquiries have been received from all the adjacent states and Canada in addition to our own state. The number of diseases diagnosed on the basis of specimens sent to the Experiment Station has been as follows:

1915—500.

1916—370.

1917—394 to January 1, 1918.

A detailed report giving the results of these examinations is being prepared.

Some of the More Important Diseases.

No attempt will be made to list all of the diseases that were reported during the year. The following are some of the more important diseases that are new to the state according to all available records:

- 1 The aecidial stage of *Puccinia Graminis* on the barberry.
2. The internal black spot of cabbage.
3. A bacterial ear rot of corn.
4. Cottonwood scab due to *Fusicladium Tremulae*.
5. Cranberry rust due to *Pucciniastrum myrtilli*.
6. Cranberry rot due to *Fusicoccum Putrefaciens*.
7. Fig cankers caused by a *Botrytis* species.
8. Gooseberry fruit spot caused by *Phyllosticta Grossulariae*.
9. A bacterial blight of the blossoms of the white lilac.
10. Citrus canker on oranges imported from Japan.
11. Peony scab due to *Cladosporium peoniae*.
12. The bacterial blight of English Walnut.

A number of diseases are of increasing importance and demand investigation either as to control methods or etiology or both. These are in addition to the projects already under investigation. The following may be mentioned:

1. The crown rot of fruit trees. Investigation of cause and prevention.

2. Apple anthracnose. A further study of the life history of the fungus and experimental work of the control of the disease.

3. Fusarium rot of onions. Etiology and control.

4. The rough bark disease of both apple and pear.

5. The leaf roll and silver leaf of the prune. The cause of these troubles is uncertain and no remedial measures are known. The silver leaf disease of Washington has not been shown to be identical with the disease of this name in other regions.

6. The cause of clover failures in Western Washington.

7. The blight of alfalfa due to *Pyrenopeziza Medicaginis*.

8. The value of spraying for potato blight in Western Washington and the distribution of this disease.

DIVISION OF SOILS

Soil Moisture Project.

The results obtained from this project covering a period of six years on the Palouse soil show conclusively that the total moisture supply to the growing plant is not affected by variations in summer-fallow tillage. It has been found that there is sufficient precipitation every winter to leave the soil in a completely saturated condition in the spring of the cropping season even though the summer-fallowing has not been practiced. The **distribution** of moisture in the soil, however, is affected by summer-fallow and by variations in the methods of tillage practiced in that some plots showed a much higher moisture content than others in the surface foot of soil. The results showed also that the moisture in the surface foot of soil if held there during the warm portion of the year had a favorable effect upon nitrification as indicated by the

increase in the nitrate content of such plots. The yield of wheat varies almost in direct proportion to the nitrate content of the soil and consequently the conclusion has been reached that the system of tillage which will keep the largest amount of moisture in the surface foot of soil during the summer-fallow year is also the system that will produce the best crops.



Fig. 3—(6) No summer fallow—20.5 bu. wheat per acre. (3) Fall plowed, early spring disked and harrowed—52.7 bu. per acre. (8) Late spring plowed and harrowed—30.6 bu. per acre.

Crop Residue and Nitrification Project.

The practice of summer-fallowing on the soils of Eastern Washington has had a very destructive effect on the organic matter which in turn has had a detrimental effect on the physical condition of the soil. The maintenance of humus in the soil requires that crop residues, green manures or barnyard manure be returned to the soil. These facts together with the experience that very unsatisfactory crop yields are often times obtained when an effort is made to increase the humus supply, have prompted this work.

A field of 36 plots was laid out to determine:—

1. Best time of year to return straw to the field.
2. Comparison between plowing under or surface dressing of straw.
3. Comparison of straw applied alone or supplemented with sodium nitrate.
4. Comparison of straw used on spring or winter grain.

Results obtained previously from the work on tillage plots have shown conclusively that nitrates in the soil are the limiting factor in crop production from the standpoint of fertility. The questions whether a commercial fertilizer containing nitrogen could be substituted for summer-fallow and whether such could be practically introduced in Eastern Washington need an answer. Plots were laid out to determine:—

1. Best time to apply a nitrogen fertilizer.
2. Amount of nitrogen to apply.
3. Comparative value of sodium nitrate and ammonium sulphate.
4. Comparative effect on winter and spring seeding.
5. Location in the spring of nitrates applied in the fall.

In connection with this work several fertilizer tests with sodium nitrate were conducted in co-operation with farmers on wheat fields in the vicinity of Pullman.

The season's results do not justify drawing conclusions without further tests.

Soil Fertility Project.

To determine the limiting factor in soil fertility 23 fertility tests were conducted in the field in co-operation with 17 County Agents. This work was supplemented by pot tests at Pullman, conducted on three different soil types with a total of 80 pots grown to oats and 30 pots grown to clover. The results from this work should prove invaluable as a means of giving definite information concerning the fertility and lime

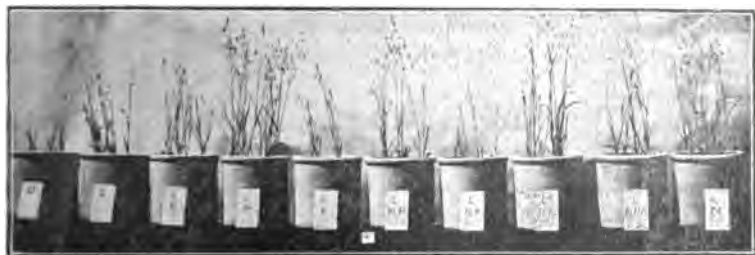


Fig. 4—A Western Washington soil—Melbourne series. A pot test which shows that the soil is in need of both phosphorus and lime, as indicated by the increased growth of oats produced on all pots that had phosphorus and lime applied.

requirements of at least a few of the important soil types in the State.

Lind Sub-station.

The Soils Department in co-operation with the Dry Land Sub-Station at Lind, Wash., is conducting tillage, fertilizer and crop residue experiments on 74 plots in duplicate. Thirty-six of these plots are devoted to tillage and on these moisture and nitrate determinations were made for the first time this year. Results indicated that there were very wide variations in the nitrate content of the different plots as affected by variations in tillage. In fact the variations in nitrates were greater than the variations in the total moisture content in the plots. This would tend to indicate that the available nitrogen supply, even in those dry land soils, may become a more direct limiting factor than the supply of moisture.

Twenty fertilizer plots were laid off in the spring of 1918 with the intention of determining the limiting factor of soil fertility, both from the standpoint of yield and quality of the product produced.

Eighteen plots were laid off to determine the value of crop residues and barnyard manure from the standpoint of time, manner and method of application.

Pot Work on Crop Residues.

Last year's report showed that an application of straw to soils in pots decreased the yield of wheat. This work was carried on again this year on another soil to check up last year's results. The following table gives the data:

Treatment	Grain gms.	Straw gms.	Total gms.
Control	5.60	16.75	22.35
Straw, 11 gms.	4.68	12.50	17.18
Straw, 22 gms.	4.65	10.00	14.65

These pots are in crop again this year so that the residual effect of straw may be determined.

Last year's report showed that when straw was applied to an alfalfa soil, which is ordinarily considered very productive, it had the same depressing effect on the yield, as is indicated in the data above. When, however, this same soil was cropped.

the succeeding year the residual effect of the straw applied the preceding year was apparently beneficial, as indicated below.

Treatment	Grain gms.	Straw gms.	Total gms.
Control	4.26	12.00	16.26
Straw, preceding year, 11 grms.	5.68	13.20	18.98

In connection with this work the pot tests on crop residues and manure both supplemented with green alfalfa were continued. It was found that the residual effect of the crop residue in the second year was also beneficial, as indicated by an increased yield of wheat. In a general way it might be stated that the application of straw has a depressing effect on nitrification and that it takes almost a year's time before this effect is sufficiently overcome to bring the crop yields back to normal. After this depressing effect is overcome the crop residue has a beneficial residual effect.

Carbon-Nitrogen Ratio in Soils.

An effort was made to determine the effect of the growing of alfalfa on the carbon and nitrogen content of soils. Soil samples were obtained from the Palouse section and also from the irrigated fields in the Wenatchee and the Yakima valleys. The tables below show the difference in the carbon and the nitrogen content of soils grown to alfalfa as compared to soils under clean cultivation.

WENATCHEE SOILS

Time in alfalfa	Soil depth considered	Increase in nitrogen in lbs., per acre	Increase in carbon in lbs., per acre
3 yrs.....	5 feet.....	580 lbs.....	15,800 lbs.
3 yrs.....	4 feet.....	69 lbs.....	4,600 lbs.
20 yrs.....	5 feet.....	2,915 lbs.....	18,250 lbs.
4 yrs.....	4 feet.....	349 lbs.....	14,000 lbs.
— yrs.....	5 feet.....	784 lbs.....	18,100 lbs.

Yakima Soils

5 yrs.....	4 feet.....	1,115 lbs.....	2,265 lbs.
5 yrs.....	4 feet.....	87 lbs.....	3,485 lbs.
15 yrs.....	4 feet.....	1,516 lbs.....	19,689 lbs.
9 yrs.....	4 feet.....	854 lbs.....	4,008 lbs.
4 yrs.....	4 feet.....	1,254 lbs.....	4,356 lbs.
5 yrs.....	4 feet.....	296 lbs.....	
7 yrs.....	4 feet.....	923 lbs.....	1,917 lbs.

PALOUSE SOILS

12 yrs.....	4 feet.....	4,150 lbs.....	71,500 lbs.
4 yrs.vetch	3 feet.....	1,093 lbs.....	25,400 lbs.

Soil Sample Tests.

About 500 samples of soil were received at the laboratory and examined. These samples were submitted by farmers from all sections of the state, indicating that the service offered by this department is not only appreciated but is utilized. In order to be of best service, in this connection, however, the department should devote more time to detailed experimental work in the field.

DIVISION OF VETERINARY SCIENCE**Goitre Disease.**

The work in this division has been confined to the one project, V. 6; Goitre and associate conditions in domestic animals. The major part of the investigation of these conditions was conducted as formerly at the temporary station located between Twisp and Winthrop, in the Methow Valley, Okanogan County.

It is gratifying to note that during the past year, experimentation with goats and sheep has yielded some extremely satisfactory and encouraging results. Three different lots of these animals which had previously given birth to goitred young, this year dropped perfectly normal young as the result of treatment with iodine, administered by different methods. The first lot was treated by giving two grains of potassium iodine daily throughout pregnancy; the second by injecting under the skin once a week throughout pregnancy, one-half mil. of tincture of iodine mixed with five mils. of water; and the third lot was treated by pouring one mil. of tincture of iodine on the back once a week throughout pregnancy. Results in all cases were uniform and the efficiency of iodine as an agent for the prevention of congenital goitre and hairlessness, at least in the case of goats, has been proven beyond a doubt. In these latter animals, it was possible to maintain absolute checks on our experimental subjects.

Constant experimentation during the past three years has failed to yield conclusive results in the case of hogs. Different varieties and sources of food and water given to sows during pregnancy, has failed to cause the farrowing of hairless pigs.



Fig. 5—A pair of stillborn and hairless kids affected with goitre. These were dropped by an Angora doe (No. 20) in the spring of 1917. No treatment was administered to this doe during pregnancy.



Fig. 6—A pair of normal twin kids dropped by the same Angora doe (No. 20) in the spring of 1918, after administration of one-half mil. of tincture of iodine mixed with five mils. of water under the skin once a week throughout pregnancy.

In practically all cases, sows at the Station have dropped normal pigs, and this without the administration of iodine. It is evident that hogs are much less susceptible to this condition than either goats or sheep.

A detailed comparative study has been made of the pathology of the thyroid glands of the various species of animals and this together with the results of chemical examination points to a like origin of goitre in goats, sheep and cattle, hairlessness in pigs and the condition commonly known as "weak colts."

DIVISION OF ZOOLOGY AND ENTOMOLOGY

The usual routine of identification of insects and other pests and of furnishing advice for their control has been greatly increased because of war-time interest in food production and conservation. The designation of the Entomologist as project leader in extension entomology and the assignment by the U. S. Bureau of Entomology of five entomological assistants has served as never before to correlate station with extension work and to carry to the public the basic investigations of this institution. Through this means this year we have informally been enabled to add to our knowledge of the work and control of such insects as the coulee cricket, strawberry root weevil and grasshoppers.

Cranberry Insects.

For several years certain newly introduced insects have been increasing to such an alarming extent as to threaten the cranberry industry of Southwestern Washington. Already several bogs have had their entire crop ruined. Preliminary surveys during 1917 showed that the main damage was done by the blackhead fireworm (*Eudemis Vacciniana*), which in its new environment had acquired habits remarkably different from its behavior in the East, being here destructive mainly to the fruit.

Since the cranberry growers petitioned the U. S. Bureau of Entomology likewise to engage in a study of their pests it

was deemed expedient to join forces and hence a formal contract was entered into for a co-operative study of cranberry insects in the region north of Ilwaco.



Fig. 7—Insectary at Seaview, Wash., used in the co-operative investigations on cranberry insects.

Among the results of this season's co-operative work may be mentioned the following:

1. The identification of the devastated species was verified, and its life cycle and fruit feeding habits investigated. It was ascertained that the times of greatest abundance of the larvae were the latter part of May for the first brood and the middle of August for the second, while unlike the eastern form, a partial third brood of larvae appeared during September.

2. Suggested methods of spraying were tested. These showed the necessity of using a spreader such as soap or glue with the insecticide. In general, better results were obtained with nicotine spray than with the customary arsenical.

3. Locally, a native weevil (*Geoderes Incomptus*) was found destructive, and the cranberry girder (*Crambus Hortuellus*) was noted as widespread though causing relatively little harm.

Independently of the co-operative study the entomologist carried on some spraying tests in a heavily infested bog, to determine if the penetration system of spraying developed at this Station could be adapted to bog conditions. Inasmuch as the over-wintering eggs and hatching larvae of the fireworm occur exclusively on the underside of the leaves within a few inches of the ground it was deemed advisable to drive a horizontal flat spray among the matted vines instead of depending on the usual mist-spray settling down from above. This test apparently has given the keynote to future spraying procedure since the area so treated developed the fewest larvae of the bog.

Immunity of the San Jose Scale to Sprays.

In order to bring together under the same environment scale insects from the several regions of the state an attempt was made to transfer such scale insects to potted trees in the insectary building. While many thousands of scales in all were transferred, being lifted off by a fine camel's hair brush immediately after birth and laid on the potted trees, the experiment was unsuccessful. For some unknown reason the transferred scales remained naked throughout their life. Most of the scales died early in the experiment; a few, however, lived to develop some strands of white wax, which failed to agglomerate and form the protecting shell so characteristic of scale insects. Those that reached maturity did not reproduce in the artificial climate of the insectary. Absolute failure has repeatedly been met in trying to get the San Jose scale to thrive at Pullman, both out of doors and within the insectary, which is rather a commentary on the usual idea that the San Jose scale is the worst orchard pest.

A more successful venture was an exchange of infested trees between Clarkston and Wenatchee. These trees were treated with identical solutions of lime-sulphur and in line with our

previous results a greater resistance to the spray was shown by the Clarkston scales. During the spring months the extensive spraying tests of preceding years were repeated at Clarkston, Walla Walla, Yakima and Wenatchee. Counts one by one of many thousands of scales at definite intervals subsequent to the spraying showed as heretofore a marked degree of difference in resistance to the polysulphide sprays according to the provenience of the insects. Scales from Wenatchee were relatively highly susceptible, while those from Clarkston showed a striking resistance.

In connection with this work tests of many insecticides were made, which have an ultimate practical bearing. The highest grade of miscible oils used at five per cent strength proved much quicker acting and more efficient than the customary polysulphid sprays, but samples of one widely used brand obtained in different localities lacked uniformity to an astonishing degree. A dry form of lime-sulphur did not measure up to the liquid in efficiency and is far too expensive for recommendation. Lime-sulphur testing three degrees Beaume is usually as efficient as a stronger spray, but where scales show a resistance to this strength they are resistant likewise to a much greater concentration. In such cases it is advisable to use a good grade of heavy oil spray.

Taxonomy of Insects.

Some technical research on the classification of certain groups of insects has been carried on in the entomology laboratories. A paper dealing with *Drapetis*, a group of predatory flies, appeared in the Annals of the Entomological Society of America, Volume XI, pages 183-221 (June, 1918). A similar study of the related genus *Platypalpus* has been made and is ready for publication. A monographic review of the scavenger and dung flies belonging to the family Borboridae has been practically completed.

Biological Survey of Washington.

In informal co-operation with the Bureau of Biological Survey of the U. S. Department of Agriculture this division made

a survey of the base of Mount Adams and of the Wenas Valley, during the summer of 1917. The entomologist similarly was afield in insect scouting work, particularly in Western Washington, going from place to place by automobile so as to come into direct contact with the insect problem of that part of the state.

ADAMS BRANCH EXPERIMENT STATION

1917 was the first crop year on the Adams Branch Experiment Station. Crop conditions were on the whole unfavorable, the late, cool spring causing slow development, activity of wire worms thinning stands, and hot summer weather seriously affecting ripening grain.

Cereals.

Because of unfavorable weather conditions, no fall sown grain on the station survived the winter. All data secured, therefore, is on spring sown varieties.

Twenty-eight varieties were tested under field conditions. In addition, over 100 other varieties were tested in the cereal nursery. The five best varieties were Early Baart, Wash. No. 618 with a yield of 13.8 bushels per acre; Karun No. 1333, 13.6 bushels; Bobs No. 1331, 13.1 bushels; Koola No. 1332, 12.4 bushels; Bluestem No. 501, 8.9 bushels.

Of the varieties tested, Early Baart is the leader. This variety of recent introduction now is widely grown in the drier sections of the state, being popular both from the growers' and the millers' standpoint.

The result of one year's test on date, rate, and depth of seeding spring wheat, is too inconclusive for report. However, in general, the early date, the heavier rates and a depth at least sufficient to prevent drying out of seed gave the best returns. One great advantage of the heavier rates lay in the more complete control of weeds.

Of the other cereals under test, the best spring rye gave an acre yield of 10.5 bushels, spring barley 16.2 bushels, and spring oats 19.5 bushels. Millets were seeded at two different dates with very indifferent results.

Forage.

Results with forage crops were not particularly encouraging. Alfalfa and sweet clover were so light in yield as to offer very little encouragement. Corn returned 7.1 bushels of grain, and 1500 pounds of stover per acre; broom corn 4000 pounds of stover per acre, and Russian sunflower also 4000 pounds per acre. Of all forage crops tried, field peas seem most promising.

The best varieties of field peas grown in 1917 and their yields were as follows: Bangalia, S. P. I. 8.9 bushels per acre; O'Rourke S. P. I. 7.3 bushels; Amraoti S. P. I. 6.9 bushels; Lima, S. P. I. ...7 bushels; Carleton, S. P. I. 6.6 bushels; Canadian S. P. I. 6.6 bushels.

Peas may offer possibilities where they can be harvested by stock, but for grain alone the crop can not compete with wheat.

Additional work in winter cereals, tillage problems, soil fertility and rotations are also under way.

WATERVILLE BRANCH EXPERIMENT STATION

Intended primarily as a forage experiment station, work on the Waterville Station combines cereal production with forage cropping.

The best yielding winter wheats were as follows: Turkey Red No. — 32.5 bushels per acre; Turkey Red No. 326, 30.4 bushels; Triplet No. 597, 29.9 bushels; Turkey Bluestem No. 540, 27.3 bushels; Hybrid No. 128, 36.2 bushels.

The best yielding spring wheat varieties were as follows: Bluestem, Wash. No. 362, 28.7 bushels per acre; Early Baart, Wash. No. 618, 26.5 bushels; Chul x Bluestem, Wash. No. 622, 25.4 bushels; White Elliott, Wash. No. 1351, 22.6 bushels.

Field peas were also grown on the Waterville Station. The best yielding varieties were as follows: Kaiser S. P. I. No. 17006, 16.9 bushels per acre; Lima S. P. I. No. 23850, 15.4 bushels per acre; Amraoti S. P. I. No. 21709, 14.2 bushels; Bangalia S. P. I. No. 21288, 13.1 bushels; Grey Winter S. P. I. No. 16436, 13 bushels.

Other crops have not been grown long enough for a report to be made.

An additional 160 acres has been leased for enlarging the station and is being put into condition for the experimental work in 1919.

PROSSER BRANCH STATION

The last legislature authorized the selection of a site for an irrigation experiment station and delegated authority to select such site to the State College of Washington. A committee

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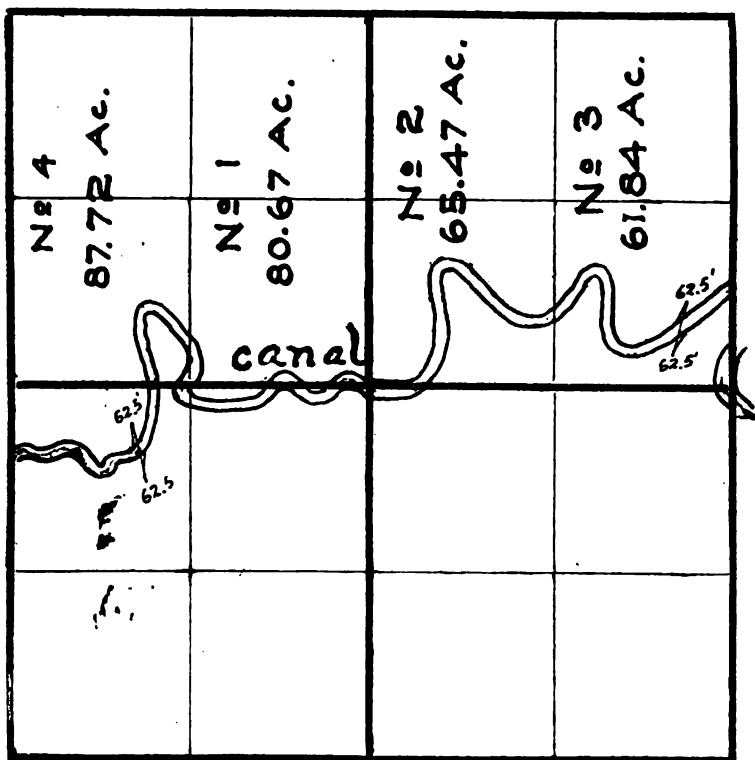


Fig. 8

Proposed Site of Irrigation Station

was therefore appointed including the Irrigation Engineer and the Assistant Soil Physicist of the Washington Experiment Station and the Irrigation Engineer of the U. S. Reclamation Service for Yakima Valley and a representative from the U. S. Department of Agriculture. Several available sites were considered and a site finally selected four miles northeast of Prosser above the Sunnyside Canal, as indicated in Fig. 8.

The Northern Pacific Railway Co. donated tract No. 1 and gave an option on tract No. 2 for \$30 per acre on condition that \$2000 be spent on improvements within one year, the option to be taken up within 30 days after the close of the sixteenth session of the Legislature. These two tracts were held under contract by the Hon. E. F. Benson, Commissioner of Agriculture, and the payments which he had made the railway company on the two contracts were accepted as total consideration for the 80-acre tract deeded to the state.

F. M. Rothrock has also granted a favorable option on tract No. 3. The soil of the entire tract of 207.98 acres varies from a light, sandy loam to a heavy, sandy loam and is well suited to the purposes of experimentation. Since this tract lies above the old ditch and is to be watered from a pipe line, there is practically no danger of seepage. The tract offers all slopes.

The citizens of Prosser donated \$3000 for the initial development of the tract and the work of clearing, plowing and leveling is in progress.

OFFICE OF FARM MARKETS

The fifteenth Legislature passed an act creating the "Office of Director of Farm Markets" with an appropriation of \$15,000 for the biennium, and authorized the Director of the Experiment Station to nominate the Director of Farm Markets and requisition the expenditure of the appropriation. The law became effective June 8, 1917, and active work began by the appointment of Asher Hobson as Director, with headquarters at Pullman. The Bureau of Markets of the United States Department of Agriculture has contributed \$1143.55 and the Extension Service of the State College \$1500.00 for co-operative work in marketing.

The office has maintained an assistant and a clerk for full time and has secured considerable aid through the hearty co-operation of the State Department of Agriculture.

The following is a brief summary of the activities of this office.

1. Organized 15 co-operative marketing associations.
2. Investigated and rendered a decision on 10 complaints of shippers of farm produce.
3. Conducted Food Survey (Federal Bureau of Markets) city of Walla Walla.
4. Addressed 196 previously advertised public meetings.
5. Participated in 192 marketing conferences with individuals and committees, exclusive of office conferences.
6. Analyzed business activities of the Washington Co-operative Egg and Poultry Association.
7. Compiled classified mailing list of growers of the state.
8. Compiled classified list of wholesale dealers of Washington farm products of Pacific Northwest.
9. Compiled classified list of farmers' business organizations of the state.
10. Issued Monthly Cold Storage Reports for state since November, 1917.
11. Published two bulletins.
12. Issued 19 circulars.
13. Contributed 16 special articles on marketing subjects to the agricultural press.
14. Conducted extensive research work on co-operative and cold storage laws in the United States.
15. Made detailed study of Public Markets in the state of Washington.
16. Issued 75 certificates of inspection.
17. Used 87,460 franked envelopes and 11,000 franked cards.

PUBLICATIONS

The following publications were prepared by members of the Experiment Station staff and published during the year:

General Bulletins.

147. Factors Influencing Water Requirements of Plants, by C. C. Thom and H. F. Holtz.
148. Evaporation of Fruit and Vegetables, by J. S. Caldwell.
149. Preparation and Use of Pure Cultures for Legume Inoculation, by C. A. Magoon and B. S. Dana.
150. Studies on the Morphology of Wheat, by G. H. Jensen.

Popular Bulletins.

112. Home Preparation of Breakfast Foods and Flour from Whole Grain, by Geo. A. Olson.
113. Potatoes (poster) Some Potato Production Requisites, by R. J. Barnett, F. D. Heald, and A. L. Melander.
114. Two Methods of Preserving Eggs, by Geo. A. Olson.

Newspaper Bulletins.

244. Silage for Horses, Sheep, Cattle and Swine, by Wm. Hislop.
245. Separate the Ram Lambs from the Ewe Lambs, by Wm. Hislop.
246. Statement of Situation Relating to the Increase of the 1918 Wheat and Rye Crop, by Geo. Severance.
247. Planting a War Wheat Crop, by E. G. Schafer.
248. Increasing Wheat Production Through Better Tillage Methods in Regions of Light Rainfall (less than 18 in.), by A. M. Richardson.
250. Sprouted Oats for Poultry, by Mrs. H. D. Whitaker.

The following Extension publications were prepared by members of the Experiment Station staff:

Bulletins.

29. The Bulk Handling of Grain on Washington Farms, by Asher Hobson.
30. Directory of Breeders of Pure-Bred Livestock in Washington. Compiled by Wm. Hislop.
35. Spraying Formulas for Garden Insects, by A. L. Melander.
36. State Plan for Increasing Food Production (for 1918), by Geo. Severance.
39. Spraying Formulas for Orchard Insects, by A. L. Melander.
41. Spraying Practices for Fruit Diseases, by F. D. Heald.
44. Selection and Care of the Dairy Herd Sire, by E. G. Woodward.
45. Dairy Feeding Chart, by E. G. Woodward and K. B. Musser.
46. Prevention of and Protection from Smut Dust Explosions and Fire in Grain Separators, by E. G. Thornton.

Circular.

4. You Can Control Stinking Smut of Wheat, by F. D. Heald.

Entomology Circulars by A. L. Melander.

1. Treatment for Insects Infesting Stored Grain, Etc.
2. Currant and Gooseberry Maggots.
3. Bed Bugs.
4. Codling Moth Spraying.
5. Bee Culture Suggestions.
6. Ants.
7. Cutworms.

Botany Circular.

2. Inoculation of Legumes, by T. J. Murray.

FINANCIAL STATEMENT

Washington Agricultural Experiment Station in account with The United States Appropriations, 1917-1918

Dr.	Hatch	Adams
Receipts from the Treasurer of the United States, as per appropriations for fiscal year ended June 30, 1918, under acts of Congress approved March 2, 1887 (Hatch Fund) and March 16, 1906 (Adams Fund)		
	\$15,000.00	\$15,000.00
Cr.	Abstract	
Salaries	1 \$ 8,648.17	\$ 9,772.06
Labor	2 2,755.47	2,154.33
Publications	3 617.54	.....
Postage and stationery	4 451.14	25.23
Freight and express	5 146.89	53.89
Heat, light, water, and power	6 32.56	11.00
Chemicals and laboratory supplies	7 25.00	665.55
Seeds, plants, and sundry supplies	8 797.58	33.82
Fertilizers	9 74.86	24.05
Feeding stuffs	10 35.75	1,514.65
Library	11 11.65	.....
Tools, machinery, and appliances	12 141.82	116.39
Furniture and fixtures	13 378.74	45.71
Scientific apparatus and specimens ...	14 189.36	255.81
Live stock	15	50.00
Traveling expenses	16 673.47	277.51
Contingent expenses	17 20.00	.....
Buildings and land	18 .....	.....
Total	\$15,000.00	\$15,000.00

FINANCIAL STATEMENT

State Funds Expended on Main Station and All Branch Stations, Including the Western Washington Station
April 1, 1917, to March 31, 1918

	State Appropriation	Contri- butions	Sales	Total
Salaries	\$19,059.12	\$ 65.00	\$ 3,326.65	\$22,450.77
Labor	10,717.31	....	2,771.08	13,488.39
Publications	3,060.72	....	2,614.17	5,674.89
Postage and stationery..	1,174.91	....	859.11	2,034.02
Freight and express	781.34	....	181.14	962.48
Heat, light, water, and power	586.90	....	206.69	793.59
Chemical and laboratory supplies	221.13	....	431.23	652.36
Seeds, plants and sundry supplies	2,732.05	20.12	1,312.68	4,064.85
Fertilizers	57.90	....	193.27	251.17
Feeding stuffs	5,760.45	....	1,372.21	7,132.66
Library	262.39	....	13.50	275.89
Tools, Mach'y and appli- ances	2,279.44	2.25	336.63	2,618.32
Furniture and fixtures..	689.45	....	96.69	786.14
Sci. apparatus and speci- mens	782.03	....	254.95	1,036.98
Livestock	250.00	....	.....	250.00
Traveling expenses	2,161.97	52.93	782.46	2,997.36
Buildings	7,599.11	....	1,347.00	8,946.11
	<u>\$58,176.22</u>	<u>\$140.30</u>	<u>\$16,099.45</u>	<u>\$74,415.98</u>
March 31, 1918, balances		63.57	5,338.89	5,402.46
	<u>\$58,176.22</u>	<u>\$203.87</u>	<u>\$21,438.35</u>	<u>\$79,818.44</u>
April 1, 1917 balance on hand		\$203.87	\$ 2,153.77	\$ 2,357.64
Receipts	\$58,176.22		19,284.58	77,460.80
	<u>\$58,176.22</u>	<u>\$203.87</u>	<u>\$21,438.35</u>	<u>\$79,818.44</u>

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F. S. WILKINS
F. C. DEPT. I. S. C.
AMES, IA.

STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISIONS OF SOILS AND
FARM CROPS

Sugar Beets Under Irrigation
in Washington

By
F. J. SIEVERS and E. G. SCHAFER

BULLETIN No. 154
March, 1919

**All Bulletins of this Station sent free to citizens of the State on
application to the Director**

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SUGAR BEETS UNDER IRRIGATION IN WASHINGTON

INTRODUCTION

The production of sugar beets requires intensive methods of culture and has often been looked upon unfavorably by the farmer who has practiced only extensive farming. That irrigation districts in the State of Washington and especially in the Yakima Valley are admirably adapted to the production of sugar beets was demonstrated by the Washington Experiment Station in coöperation with numerous farmers before the year 1900.* The yields obtained and the quality of the product in many instances since then have shown that the early conclusions were correct.

It was not until 1917 that sufficient interest had developed to result in the establishment of a beet sugar factory at Yakima. The results of the first year were very encouraging and led directly to a greatly increased acreage and the construction of two other sugar factories in this Valley: one at Sunnyside and another at Toppenish.

The 1918 crop was not as successful as the growers had hoped it would be. Many of the partial failures, however, can be traced to preventable causes. A close study of the requirements of sugar beets and a firm determination on the part of the grower to meet such requirements should establish the beet sugar industry permanently in the State.

THE INFLUENCE OF CLIMATE

Very few of the general farm crops grown are as sensitive to variations in climatic conditions as sugar beets. A high percentage of the failures in the early stages of the sugar beet industry were no doubt caused by the lack of appreciation of this fact. Since then, however, experiences in the culture of this crop both in Europe and at home have

*Buls. 15, 26, 31, Wash. Exp. Sta.

shown quite specifically its limitations and requirements from many standpoints including climate. It is the intention here to compare the climatic conditions prevailing in the irrigated areas of Washington to ideal conditions for this crop as far as known, and also indicate how some of the climatic factors can in part be controlled artificially.

Sugar beets have been grown most successfully in that belt in the United States where the average temperature during June, July, and August, the three best months of the growing season, has been not more than 70 degrees Fahrenheit. Most of this data, however, has been obtained in the humid sections of the country where irrigation is not practiced, and where the variation between the night and day temperature is not very great. In the irrigated sections of this state the average temperature for June, July, and August is practically 70 degrees Fahrenheit. The daily range in temperature, however, will often exceed 50 degrees which is much greater than that of humid regions. This range means that the temperature during the day-time may frequently run up to 100 degrees, and above, a condition which may be very detrimental to the best growth of beets where moisture is limited or where irrigation is not efficiently and correctly practiced. On the other hand this temperature may be a benefit when it occurs at a time and under conditions where the moisture supply is adequate to prevent the plant from wilting. The absorption of carbon dioxide and water and the production of starch and sugar does not go on at its maximum when the plant is partly wilted. This is a fact that needs to be fully appreciated, and has a direct bearing upon efficient irrigation and cultivation, and consequently this matter will be treated more fully under these respective headings.

Sunshine is necessary for the development of sugar in all green plants, and since the value of this particular crop depends entirely upon the amount of sugar produced per acre, it is justifiable to give some consideration to the matter here even though its amount and intensity are not subject to artificial control. It is a well known fact that sunlight may be too intense for maximum sugar production, in that this process in the plant is carried on at its best in the middle of the forenoon and afternoon rather than at the time when

the sun is at its highest. A long period of partly subdued light is more desirable than a shorter period of more intense light. The latitude of Washington is such as to provide a long period of sunshine during the growing season while the intensity of light, at no time, is as extreme as would be experienced in latitudes where the rays become more nearly vertical. This, together with the fact that the State is favor-



Fig. 1. A Model Mature Sugar Beet. This beet was grown on the Western Sugar Company's farm at Billings, Montana, and shows many desirable characteristics, such as the small root crown, the gradually tapering root, the one continuous root seam of proper depth, the small twist at the lower end of the root seam, and the well pronounced wrinkles on the surface, which indicate high sugar content.

ed with a high percentage of clear days in the summer as is evidenced by the low precipitation during this season of the year, is no doubt largely responsible for the high percentage of sugar reported for beets grown in the Yakima Valley.

The velocity of the wind is an important factor because many soils that are suitable for irrigation contain high percentages of sand and are subject to blowing. On the other hand, the effect of winds on evaporation is not nearly as pronounced in an arid and consequently irrigated section as it would be under conditions of greater humidity. The atmosphere in an arid section contains a very low percentage of moisture and evaporation will practically be at a maximum irrespective of any circulation,—a condition that is quite the reverse in humid regions.

Mature sugar beets are very hardy and will withstand extremes in climatic conditions better than most cultivated plants but the young plants when first appearing above the ground are extremely sensitive to low temperatures, and although they may not be directly injured will grow very slowly under such conditions. Compared with other plants, sugar beets require a long period to reach maturity, and most irrigated sections in this state have growing seasons sufficiently long to make possible the successful growth of this crop without the necessity of chancing late frosts in the spring or cold weather early in the fall.

THE SOIL

In common with most other cultivated crops, beets can be grown on almost any type of soil, varying all the way from sands to clay loam. They will best adapt themselves, however, to a sandy loam soil. Arid soils are comparatively rich in available plant food as a direct result of the fact that they have been weathered by the forces of nature for a long geological period, and the rainfall has never been sufficient to cause an extensive loss of the soluble plant foods by leaching. The native vegetation although sparse has been sufficient not only to protect these areas against blowing, but also to incorporate considerable organic matter in the soil.

In preparing such lands for irrigation after they have been cleared, it often becomes necessary to do considerable leveling of the surface in order that water can be efficiently and satisfactorily applied. This practice frequently disturbs the upper layer of soil to such an extent that nothing but

sub-soil appears on the surface of the prepared area. This condition makes these soils comparatively unproductive for the first few seasons. The smoothing of the surface of an extensive area, and the consequent presence of sub-soil at the surface unfortunately produces conditions for the detrimental effects of blowing. Very commonly fields that required a great deal of leveling will undergo considerable settling after water is applied, and the filled in areas will frequently become sufficiently depressed to prevent the uniform flow of irrigation water. All of these factors make it unwise to introduce a crop that requires intensive care and much expense, on new lands and this applies especially to sugar beets. The soil chosen for this crop should be one that gives every assurance of success as indicated by returns of preceding years.

Most root crops including sugar beets require large amounts of nitrogen and potash and are favorably affected by a liberal supply of humus in the soil. Practically all of the irrigated soils in this state are more deficient in nitrogen than in any other one of the plant food elements. Provision must therefore be made to artificially supply this element in order that agriculture on these soils may not only be immediately but permanently profitable. A legume such as alfalfa has a tendency to maintain the nitrogen supply because it has the power of taking this element from the air and incorporating it in the soil. The nitrogen taken from the air is not only sufficient to supply the needs of the alfalfa plant, but is usually enough to furnish a few succeeding crops with this necessary element of plant food.

In growing sugar beets or any other cultivated crop on these irrigated lands, success cannot be expected unless they are fitted into a system of rotation where a legume is grown for at least one-fourth of the time. This matter, however, is of sufficient importance to deserve special consideration and will therefore be treated under a separate heading.

It is fortunate that fine sandy loam soils are so well adapted to the growth of beets because these soils have ideal physical properties from the standpoint of a crop that requires intensive tillage in its early stages. Sandy loams have the advantage of not only being easily tilled at a minimum expense,

but their surface dries out very rapidly after an irrigation. This permits cultivation very soon after the water has been applied without danger of puddling. Such early cultivation prevents weeds from getting a foothold.

The expense of raising sugar beets is very decidedly affected by the ease with which the weeds can be controlled, and this control depends largely upon how close the horse cultivator can be run up to the rows when the plants are young. Clay soils that are inclined to bake and become lumpy will not permit this close tillage because of the tendency to cover the young plants. Sandy soils are subject to blowing, and this destructive effect upon the young plants must be given foremost attention in all operations pertaining to the culture of sugar beets on light soils.

PREPARATION OF SEED BED

The preparation of the seed bed in the growing of sugar beets is perhaps the most important operation. Primarily this is true for the reason that sugar beets from a cultural standpoint are really a truck crop, but are grown by the general farmer who is not familiar with the detailed tillage methods employed by the truck farmer. Simply preparing the seed bed and immediately planting the crop, a practice commonly followed in general farming, is not satisfactory. It must be fully appreciated that this is a crop that will present a decided weed problem and requires much unnecessary hand labor if improperly handled in the early stages.

All land for sugar beets, whenever possible, should be plowed in the fall. As soon as the season opens up in the spring sufficiently to allow good tillage, the field should be disked. If the soil is not subject to much blowing, the field may then be harrowed. Harrowing, however, is an exceedingly dangerous operation if the soil has a tendency to be easily transported by the wind. Under such conditions this operation should be eliminated. The first disking should be followed by two succeeding diskings at intervals of about ten days each. These tillage operations will produce a mulch on the surface of the soil early in the season which will conserve the winter rainfall or moisture of winter irrigation if

such has been practiced. In this manner two or three crops of weeds are killed before the sugar beets are planted, and this is all done at a time when the work can be carried on with least expense.

Fall plowing followed by three diskings in the spring, will usually firm the soil sufficiently to present a good seed bed for planting the crop. If the surface of the field at this time appears too rough for the satisfactory operation of the seeder or beet drill, it may be advisable to run a corrugated clod crusher over the soil in a direction at right angles to the direction in which the beets are to be planted. Seeds planted under these conditions are not only incorporated in the soil at a uniform depth, but they are sufficiently well supplied with moisture to make rapid germination possible. The roughened surface produced by the corrugations of the clod crusher will also lessen the tendency for the soil to blow.

If beets are to be planted on spring plowing, it is unfortunate, and some difficulties will be encountered in keeping sufficient moisture near the surface for good germination. Under these conditions a good stand can be expected only after the soil has become thoroughly compacted by means of a corrugated roller or a sub-surface packer. Such tillage provides a condition that allows the moisture from below to rise sufficiently by capillarity to overcome this difficulty.

If the winter rainfall is not sufficient to furnish the proper amount of moisture, the soil should be irrigated at least four weeks before planting. If this irrigation is supplemented with the tillage recommended above, ideal conditions for the germination of weed seeds are established very early in the spring. Thus after the field is disked three or four times it is practically clean when planted and there are very few weed seeds left in the soil that are capable of germinating. Many discouragements and failures in beet culture can be traced to the lack of proper weed control before the crop is planted. The two extremes in conditions are: first, where the whole field is green with small weeds before the beet seeds have sprouted and grown sufficiently for the plants to reach the surface of the ground,—a condition that makes hoeing necessary even before the crop is ready to be thinned;

and second, where the beet seeds will be the first seeds to send their shoots above the ground and hoeing is hardly necessary throughout the season, except at the time of thinning.

PLANTING THE SEED

The beet crop should not be planted until the soil has warmed up sufficiently to cause rapid germination of the seed. It should be the aim, however, to do the planting as soon as the soil is in proper condition. Planting which is delayed too long, will reduce the length of the growing season and a long season is necessary for the production of a maximum crop. Delay in planting after the soil is in proper condition may result in drying out the surface soil and leave



Fig. 2. A Good Stand Generally Means a Profitable Crop. A perfect stand of beets will produce more than twenty tons per acre even under conditions where the average weight per beet is only one and one-half pounds.

insufficient moisture for germination of the seed. The best date for planting sugar beets will differ with different seasons. They should be planted after the spring grains such as wheat, oats and barley, but before the best time for

planting corn. The time for planting should be governed entirely by the season and the condition of the soil. Early planting is not only desirable in that it prolongs the growing season but aids in combatting many insect pests and diseases.

The amount of seed necessary depends upon its quality and size. It is desirable to have seed of high per cent of germination and free from foreign material. The seed of the sugar beet is contained in seed balls. The number so contained is not uniform and if the seed balls are small, a larger number will be required to make a pound and a less amount by weight is necessary to plant a given area. Because of the character and condition of the seed it is impossible to secure a complete stand without providing at planting time for more plants than are actually necessary. Fifteen pounds of good average seed will usually be sufficient to plant an acre.

The rows should be about twenty inches apart. A wider spacing will have a tendency to produce large beets, especially if the soil is rich and growing conditions favorable. Very large beets are not desirable since a larger number of beets of normal size resulting from closer spacing will yield as large a tonnage with less waste in topping and a product of higher sugar content. Rows should be spaced wide enough apart in soils of medium fertility to produce a medium sized beet. Soils of low fertility should not be used for sugar beet growing. Rows spaced from twenty to twenty-four inches apart are cultivated and irrigated more easily and at less expense than when closer together. When growing sugar beets for the first time much difficulty in cultivating and caring for this intensive crop may be eliminated by wider spacing. After the grower more thoroughly understands the practices employed in sugar beet culture he will be able to successfully grow the crop with the rows closer together.

The exact depth depends upon the condition of the soil. The seed may be planted at a greater depth in the sandy loam soils of this state than in heavier soils commonly found in some of the older sugar beet sections. It is essential that the seed be placed in moist soil to promote rapid germination. If the immediate surface does not contain sufficient moisture

or if it is likely to dry out before the young plant becomes established, the seed must be planted at a greater depth. If the seed is planted too deep the food or energy contained in it will be expended before the plant reaches the surface. Usually it is not advisable to plant more than one and one-half inches deep. Planting at a uniform depth will aid in getting an even start of the young seedlings. Fields having a uniform growth of vigorous plants may be thinned earlier and the amount of hand labor for their early care is reduced.

The seed is commonly planted with a four row drill especially adapted for this crop. The soil above the seed should be packed sufficiently to establish moisture connec-

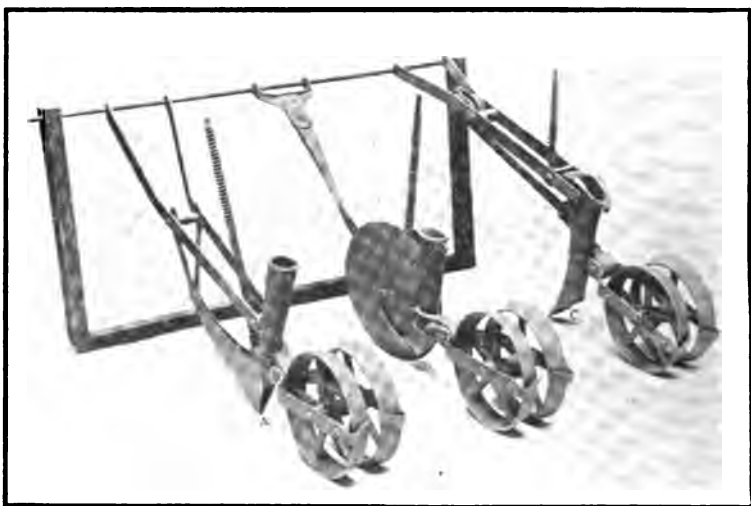


Fig. 3. Three different types of drills used for seeding purposes.

tions with the soil below in order to obtain the best conditions for immediate germination. The beet planter both opens a furrow to receive the seed and covers the seed at the same time. Several different methods of performing this operation are possible with different types of seeding machinery. Three of these types are illustrated in Fig. 3.

The one shown in A is known as the shoe drill. It has a closed bottom and has a tendency to pack the soil just be-

neath the place where the seed is dropped. This is a desirable type of drill on sandy loam or on any other soil that is so loose that it needs additional packing. The one shown in B is known as the disk drill and is extensively used for seeding different kinds of grain on various types of soil. It does better work than any other on land that contains trash and waste material. Lands in such condition, however, should not be used for an intensive crop like sugar beets. The one shown in C is known as the hoe drill. It has a tendency to loosen the soil on land that has been packed too firmly. It is, however, not likely that the sandy loams of this state where sugar beets are grown will be too firm.

Another attachment should immediately follow the planting device to pack the soil firmly over the seed. This may consist of either an open or closed wheel. The open wheel has the advantage of firming the soil from the sides of the seed row, leaving it less firm immediately above. This prevents a crust from forming right over the row and the small seedlings will have less difficulty in emerging from the soil. The open wheel with a concave surface will leave the center of the row slightly ridged and there will be less danger of covering the small plants at the time of the first cultivation.

In the early stages of the industry beet planting machines are commonly furnished and the planting is done by the beet sugar companies who contract to purchase the crop. Such attention given by the company insures a uniform method of planting and a good grade of work. It is perhaps most desirable to have such an arrangement while the grower is inexperienced in growing the crop. If sugar beet production, however, becomes permanent in the cropping system of the individual farm the grower should doubtless own his own planting machinery. He will thus be enabled to more nearly control the time of seeding his crop than if he is dependent upon some one else to do it. The importance of seeding at the proper time cannot be over-emphasized because of the direct effect on the stand and yield. The rows should be as nearly straight as it is possible to make them. Straight rows can be irrigated more easily and horse cultivation can be practiced earlier and therefore more effectively.

THINNING

As stated previously the nature of the beet seed together with the importance of having a uniform stand, makes it impossible to space beets properly when planted. It is, therefore, necessary as soon as possible after all of the plants



Fig. 4. An Indication of Rare Adaptability. Over sized sugar beets may lack quality and cause large waste in topping, but they certainly are an indication of suitable soil and climatic conditions. Eighteen pound beets were quite common at Sunnyside, Washington, in 1918 and a portion of one field produced at the rate of forty tons per acre.

are up and most of them have developed about four leaves to do the required thinning in order to space them at the right distance in the rows. This work requires a certain amount of human judgment and is best done by hand. It can usually be

handled to best advantage by dividing it into two separate operations.

The first of these, called blocking, is performed by following the rows with a sharp hoe and cutting out most of the beet plants in the row leaving only small groups or blocks of plants at intervals of from eight to twelve inches. Each one of these bunches will eventually be represented by one plant. A soil in good state of fertility, as indicated by previous crop-producing power or brought about by fertilization for this crop, will support more plants per acre than one less fertile and the spacing should be made accordingly. Beets spaced too wide in proportion to the fertility of the soil either do not produce a maximum yield or else have a tendency to grow abnormally large. Such large beets besides running lower in the percentage of sugar, will tare very heavily when marketed. The lack of uniformity in the size and distribution of plants in the row as planted, makes it unwise to adhere mathematically to a definite spacing in order to obtain the most desirable stand. This is the main reason why machines constructed to do this work have been unsatisfactory. A responsible workman equipped with a sharp hoe of known and sufficient width, should space very accurately and can cut the complete space between blocks with one stroke.

The second process in this practice of thinning consists of eliminating all but one beet in each block. This requires detailed hand labor, and is best accomplished by pulling all but the best plant in each block. Thinning must be done with sufficient care to prevent more than one beet in any bunch because in common with all other root crops more than one plant in a space is rarely a success. In case a field is foul with weeds it will be necessary for the worker to carry a short-handled hoe or weeder with him at the time this work is done in order that thorough and complete cultivation can be given the plants in the rows. At this time, it is well to level the ground or even hill it slightly around the plants. This will make it much easier to run a horse cultivator between the rows in the early stages of the crop without much danger of covering the small plants.

The value of proper preparation of the seed bed in the spring before planting bears repetition here. It is con-

servative to estimate that the cost of thinning a weedy field may easily be twice as high as for a field properly prepared. When it is taken into consideration that thinning is one of the most tedious and expensive operations in the whole system of beet cultivation, the importance of the weed problem becomes very apparent. Whatever the conditions, the beet row after thinning should be perfectly clean. The thinned beets will look sickly and wilted for a short period after the surrounding plants have been removed, but will soon take advantage of this lesser competition for plant food and moisture and produce stocky healthy plants.

INTER-TILLAGE

The first inter-tillage should be given before thinning and as soon as the plant is of sufficient size to make such cultivation possible. Under best conditions, the hoeing given the crop at the time of thinning is practically all of the hand cultivation required. After this stage, all cultivation is done by horse power and should be frequent so that all beneficial results depending upon this practice may be obtained. Besides destroying weeds, proper cultivation will form a mulch of loose soil on the surface that will prevent the rise of capillary water and in that way conserve the moisture in the soil and retard the rise of alkali salts to the surface. This stirring of the soil also provides for the aeration so necessary for the decomposition of manure, crop residues and other organic matter. Without this aeration, the plant food stored up in these organic substances would not become soluble and the plants would suffer for want of a sufficient available food supply. This applies especially to the element nitrogen so frequently deficient in irrigated soils.

The second cultivation should be given immediately after the plants have overcome the effects of thinning. This cultivation should be sufficiently shallow to permit working as close up to the row as possible without danger of covering the plants. There is not much danger of injuring the root system of the plants at this time because the lateral roots are just beginning their main development. In subsequent tillage, it must be borne in mind that these lateral roots extend entirely across the rows before the small beet is even

one inch in diameter. Since these laeral roots are comparatively near the surface and absorb most of the plant's food supply, any cultivation that is deeper than necessary to form a good mulch may be decidedly injurious. Stirring the soil to a depth of three to four inches will generally accomplish everything required for good cultivation, and will permit the moisture to come sufficiently close to the surface to aid in the decomposition of manure and other organic matter found there.

The field should be cultivated as soon as possible after every irrigation in order to conserve the moisture, but this amount of cultivation is not at all sufficient to accomplish all of the other results depending on this operation. For instance, there were splendid beets grown in the Yakima Valley in the season of 1918 on land that was sufficiently sub-irrigated not to necessitate the direct application of irrigation water. From the standpoint of moisture, these plants would not need any cultivation. Nevertheless, experience with other cultivated crops has convinced most farmers that weeds are most easily killed before they ever appear above the ground, and that in order to avoid their appearance, it becomes necessary to till the soil once every ten or twelve days during the early growing stages of the plants. As stated above, frequent cultivation is necessary to stimulate the development of available plant food even if there are no weeds to kill.

About the time that the plants are sufficiently large to have their tops nearly cover the ground, the cultivator should be so adjusted, if possible, to till shallower near the row than in the middle. Such adjustments prevent unnecessary injury to the lateral roots near the row where they are close to the surface. At the same time thorough cultivation is provided between the rows where the ground is not covered by the beet foliage and where weeds consequently have a greater tendency to grow.

The normal beet grows almost entirely in the ground and will not stand much hilling. This fact makes it quite difficult to cover up by cultivation all weeds that get started in the row, and therefore it may become necessary to run through the field with a hoe for the purpose of cutting out those straggling weeds before they become sufficiently large

to draw very heavily on the moisture and plant food supply. The cultivating implements used for this work are frequently supplied by the company contracting for the beets, but unless the area grown is decidedly small, every grower should plan on having his own equipment in order that the most timely tillage may be practiced.

The implements used should conform to the seed drill in that a four-row drill is best followed by a four-row cultivator. By tilling the same four rows together that were planted together, it is possible to work nearly as close up taking four rows at a time as would be possible with a one-row implement. All possible injury to the main tap root should be avoided because such injury will generally cause the plant to make an abnormal root development detrimental to the best quality for sugar production.

IRRIGATION

Any system of farming that includes the growing of intensive crops should be carried on under conditions where most of the factors essential for plant growth are almost absolutely under control. Of all the controllable factors that limit crop production, the proper amount and supply of moisture is perhaps most important, for ordinarily if a plant receives the right amount of water at the proper time during the growing season, reasonably satisfactory results are assured.

Irrigation, when correctly practiced, will be effective in supplying to a plant the proper amount of water at the right time. To be an efficient irrigator, one must thoroughly understand the nature of plant life, and also the action of water after it is applied to the soil. (Variations in soil texture have a direct effect upon the amount of water a soil will hold, upon the rapidity with which moisture will distribute itself after applied and also upon the percentage of moisture in the soil that is available for plant use.

The following diagram, based on data obtained in irrigation work at Grandview, Washington, will give a definite idea of just how the water will travel through the soil, and also the length of time that it takes for this passage.

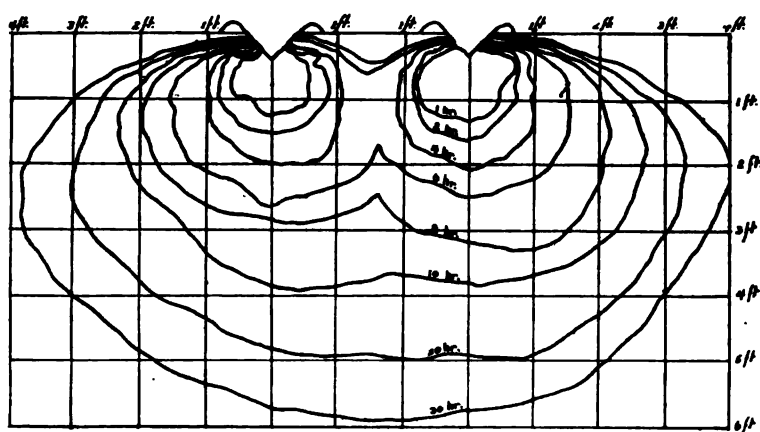


Fig. 5. The Distribution of Irrigation Water in Soil at Grandview, Washington. The distributon of water is affected by various soil conditions and consequently is not the same for all soils. Intelligent irrigation requires a knowledge of this distribution such as can be obtained only by frequent but consistent use of the soil auger.

Plants also have their variation in total water requirements as well as in the effects of this water when applied at different stages of plant development. Table I. submitted herewith gives the definite amount of water transpired by various plants for the production of one pound of dry matter

TABLE I.

The Amount of Water Transpired by Various Plants under Conditions at Pullman, Washington

Crop	Yield	Total Wt. of plants per acre	Total Wt., dry matter per acre	*Water transpired per lb. of dry matter	Acres actually transpired
Wheat	60 bus.	9000 lbs.	8280 lbs.	361 lbs.	13.17 ins.
Oats	90 "	7200 "	6624 "	345 "	10.06 "
Barley	75 "	9000 "	8280 "	320 "	11.68 "
Corn	100 "	11200 "	10080 "	249 "	11.05 "
Peas	35 "	6300 "	5796 "	420 "	10.73 "
Millet	3 tons	6000 "	5400 "	279 "	6.64 "
Sugar beets	20 "	50000 "	10000 "	435 "	19.22 "
Beans	30 bus.	5400 "	4968 "	444 "	9.72 "

*Bul. 146, Wash. Exp. Sta.

as found under climatic conditions prevailing in the Palouse region of Eastern Washington. These also show the amount of water that would be required for transpiration in the form of acre inches to grow what would be considered a normal yield of these crops.

Sugar beets are an intensive crop and require not only a large expenditure in labor, but also heavy irrigation. As stated before they grow best on sandy loam soils and these soils are especially well suited for irrigation. This fact, together with its favorable climate, makes Washington well adapted to the growth of this crop. Since most of the natural precipitation in the State occurs in the winter season, there is generally sufficient moisture in the soil during the spring time to promote good germination. On the other hand, the soil is an enormous reservoir and can hold large quantities of water if completely saturated. This fact makes it desirable to apply heavy irrigation during the late winter or early spring when water is plentiful and when the preceeding crop was not irrigated late in the summer.

Water applied during the cool portion of the year is not lost to any extent by evaporation, but will soak into the soil to a depth of eight to ten feet to be held there for use during the growing season. Practices of winter irrigation will also tend to avoid the development of a hard pan close to the surface, a condition so common in some of the older irrigated sections. This hard pan is generally formed at a depth in the soil to which the water has penetrated after continued irrigations. If these irrigations are light and consequently frequent, this hard pan will develop so close to the surface and become sufficiently impervious that it will interfere with the normal development of plant life. A thorough winter irrigation together with the natural precipitation should leave the soil in splendid condition for the germination of seeds early in the spring. If this irrigation is necessary the water should be applied sufficiently early to give the farmer at least three or four weeks' time to cultivate his soil by disking before the beet seed is planted.

In cases where there is every evidence that the moisture at planting time is not sufficient for proper and uniform germination, irrigation water may be applied either

before or right after the seed is planted. Unless the soil is very porous the field should never be flooded, but the water should be applied in furrows between alternate rows.

The desirability of having a field well leveled becomes very evident when grown to this crop, and under no conditions should sugar beet culture be attempted on land that is not sufficiently graded to permit the uniform flow of water. An elevation of the surface which causes the water to become retarded in its flow will produce an area immediately above this elevation where the soil will become water-logged and unsuited for the growth of this crop. Several beet areas in the Yakima Valley that produced a crop which averaged twenty tons per acre during the 1918 season showed spots of from one-fourth to one-half acre in extent where the crop was completely drowned out. This was the direct result of the necessity of applying large quantities of water at such points in order that the water might rise sufficiently to flow to the lower portion of the field. A loss of from fifty to one hundred dollars in crops, resulted from the failure of such areas. The labor lost by attempting to grow a crop under these extremely adverse conditions was generally sufficient to do the leveling necessary for its prevention.

The best irrigation for all crops, and especially for sugar beets, should be so gauged that the water will not run into any furrow faster than it can be taken up, but sufficiently fast to avoid over irrigating the upper portion of the field before the lower portion is satisfied. The length of the furrow should be determined by the texture of the soil. On very porous soils the irrigation furrows should therefore be comparatively short. On less porous soils there is danger of an accumulation of water at the lower end of the furrow. If this condition cannot be avoided by proper regulation at the source, provision for drainage must be made at the lower end of the furrow to carry away all excess water. This will prevent the lower ends of the rows from being drowned out—a condition too commonly found.

All irrigated lands in this state contain sodium and potassium salts in abundance. These salts are all soluble and a liberal supply of water will dissolve large quantities, thus forming a dilute solution in the soil. After evaporation and

transpiration have proceeded for some time, and the moisture supply becomes diminished, the tendency is for this solution to become very concentrated. If the next irrigation is much delayed this concentration may reach a degree sufficiently high to prevent the normal functioning of the roots and cause an abnormally wilted appearance of the plant and a condition of little growth. The destructiveness of these salts is rarely serious if they are not allowed to accumulate at or near the surface. There is a tendency, however, for this to occur, and it is well to understand fully the action of soil water in order to avoid such losses in crops as were experienced in the 1918 season.



Fig. 6. The Results of Improper Irrigation. To prevent beets from drowning out at the lower ends of the furrows the water must be regulated properly at the source. If this is impossible surface drainage must be provided at the lower end of the field.

Before irrigation was provided for these arid soils, the natural precipitation did not penetrate more than several inches, and very small quantities of the salts were dissolved, and consequently there was comparatively little alkali found deposited on the surface of these soils in their virgin state. Irrigation water, however, acts quite differently, and when it is applied it passes downward through the soil rapidly and to a considerable depth. It is prevented from remaining in con-

tact with any portion of the soil long enough to dissolve much of the salt present. It is extremely difficult, therefore, to wash alkali that has once become deposited upon the surface back into the soil without resorting to flooding. In contrast, however, after the water has reached its maximum depth in the soil and during the interval between irrigations, it gradually works its way back to the surface. This upward movement is very slow, and the result is that large amounts of these salts in the soil are dissolved so that this water becomes very nearly saturated as it nears the surface. If no provision is made in the formation of mulch by cultivation, this solution will reach the surface and the water will be evaporated



Fig. 7. The Survival of the Fittest. Sugar beets can withstand large amounts of alkali in the soil but they also have their limitations. Salt grass, an alkali loving plant is gradually creeping into a field where the alkali was too strong for the growth of beets.

leaving the salts behind in a white or dark brown deposit, depending upon whether it is white or black alkali. This condition is produced most frequently where the irrigator has not yet appreciated that water cannot be substituted for cultivation but that the two must go hand-in-hand for the best results. It was found with but few exceptions that the patchiness caused by missing beets on well leveled fields in the Yakima Valley during the 1918 season could in large

part be traced to the fact that alkali was allowed to accumulate on the surface as the result of lack of timely cultivation. This condition prevailed in spite of the fact that sugar beets are possibly less sensitive to alkali than most agricultural plants not excluding such resistant crops as alfalfa and barley.

It is generally conceded that a sugar beet will not withstand more than from .4% to .6% of total alkali salts, nor more than .1% to .2% of black alkali. There is, however, no general rule that can be applied to all conditions because of the many factors that effect the action of these alkali salts. Young plants of even very resistant crops and also those plants that are shallow-rooted are most sensitive because the greatest concentration of salt is found near the surface where the main portion of their root system is established. Extreme care must be exercised in starting any crop on alkali land in that an attempt should be made to distribute these salts through a considerable layer of soil early in the season. A very high percentage of alkali on the surface may even prevent the seed from germinating.

The distribution of alkali referred to may be accomplished by flooding during the winter and subsequent tillage early in the spring. Coarse textured soils like sand or sandy loams will not hold, without detrimental results, as high a percentage of alkali as those of finer texture like clay loam or soils containing considerable organic matter. This is one reason why alkali soils that have been manured or those that have been cropped to alfalfa for several years are decidedly benefited.

The black alkali is much more destructive than the white because the former has a caustic action which will dissolve organic matter and cause the roots of plants to become corroded while the latter has only a physical effect in causing a concentration in the soil solution to the extent that plants cannot take up the moisture necessary for growth.

The methods used for the application of water up to the time of planting this crop are practically the same as for other crops with such exceptions as are covered under the heading "Preparation of Seed Bed." The preceeding discussion under this heading should convince the grower against the

practice of flooding a field planted to this or any other cultivated crop except on extremely porous soils where the border system of irrigation may be resorted to. Irrigation by flooding makes it impossible to properly maintain the mulch so necessary for the conservation of moisture and may cause the plants to be effected by sunscald as a result of too much water on the ground near the leaves. The set back thus caused may be very disastrous to the yield.

All irrigation for this crop should preferably be by the furrow system. The furrows should be run between alternate rows when the rows are about twenty inches apart because the soils in this state are sufficiently porous to permit good distribution of water at this distance. This, together with the practice of making the furrows as narrow and as deep as the width of the row and the texture of the soil will permit, will be very effective in producing the most rapid percolation with the least loss by evaporation.

The furrows for the next irrigation should be alternated with those of the one preceding it. Sandy loam soils are inclined to wash if the current of water is too rapid, and if possible the location of the beet rows should be such as to permit a furrow with a gradual slope that will develop a flow of water about one to one and one-half feet per second.

The beet roots will penetrate the soil to a considerable depth, depending upon the physical condition and the moisture supply of the sub-soil. It is therefore more important to supply water in sufficient quantities to allow it to penetrate to a depth of four or five feet after each irrigation than to irrigate more frequently to lesser depths. The depth to which water has penetrated should be known and this as well as the time required for such penetration can best be determined by borings made with a soil or post-hole auger.

The frequency of irrigation is best governed by the effect on the plant which will soon present a wilted appearance if the moisture supply is insufficient. It is, of course, common to all plants to appear wilted for short periods during the hottest part of a real warm summer day, and this condition should not be considered serious. If, however, the plants do not freshen up during the night, it is high time for the application of more water because normal growth cannot take

place under these conditions. Extended periods of lack of proper moisture will cause a decided setback and when water is finally applied an abnormal development of the plant may result. This abnormal development presents itself in the growth of a large number of small new leaves in a rosetted arrangement on the crown, and in the formation of a divided tap root with large masses of secondary roots. Not only drought, but alkali injury, disease, insect pests, etc., may



Fig. 8. Quality and Yield of Sugar Beets Generally go Hand in Hand. Any set back to the growing beets caused by excess alkali, improper water supply, severe insect injury or disease affects both yield and quality. In Nature's attempt to overcome such set backs, a divided tap root and a rosetted top as indicated by the beet on the right, generally result.

bring about a similar second growth which is not only detrimental to the yield of beets, but to their quality as well.

Where the soil is well supplied with moisture in the spring there is little need of irrigation before July. The

beet makes its most rapid growth during July, August and the early part of September. The large foliage developed during this period will draw very heavily on the moisture supply. Possibly 80 per cent of the total moisture required for the development of the plant is used during this period. Notwithstanding this fact, however, the plant should never be allowed to suffer for want of water during its early stages of growth. The last irrigation of the season is also governed by the demands of the crop. The largest tonnage as well as the greatest amount of sugar per acre is produced under conditions in which the plant has sufficient water during the latter part of the season. Intentionally withholding the water to cause early maturity, therefore lowers the yield and is not to be recommended. Conditions are known where irrigation water was applied with good results even as late as ten days before harvest. More than four irrigations are rarely necessary and under proper management and good soil conditions two may be sufficient. It is difficult to state definitely how many acre inches of water should be applied because of variations in soil texture, in per cent stand, etc., but the amount applied each time should be sufficient to fill the soil to its full capillary capacity. The fact should always be borne in mind that there is a limit beyond which water cannot be applied economically even though a slight increase in yield may be produced. The cost of the water together with the expense involved in its application may be more than such increase in yield will justify.

HARVESTING

Since the beet makes the major part of its growth in the later part of the growing season, harvesting should be delayed until late fall when the crop has reached its full size. The proper stage for harvesting is usually accompanied by the appearance of a yellowish or brownish tinge on the leaves and a general drooping condition. The fact that less dirt is retained on the root when pulled is a farther indication of maturity. It is difficult to transmit exact information concerning the way the crop should appear at the time it is ready for harvest by a description of its characteristics at that time. Persons familiar with other farm crops know

that information concerning maturity can only be obtained by experience in the field. For this and other reasons that are beneficial to the entire industry the sugar companies that contract with the grower generally decide when the crop is ready to harvest.

A beet lifter is used to loosen the roots in the soil, after which they may be removed by hand. The machine most commonly used has two prongs and when in operation these are drawn through the soil one on each side of the row. They run deep enough to loosen the beets and are inclined sufficiently to raise them partly out of the ground. The value of having the beets in straight rows again becomes apparent. The driver should operate the machine with as much care as possible so as to prevent bruising, or breaking the tap-roots too near the body of the beet. Bruises and other injuries that the beet may receive are likely to cause losses by rotting and by decreased weight due to more rapid evaporation at the point of injury.

After pulling the beets a hand knife is commonly used to remove the tops. A prong or pointed spike protrudes from the edge of the knife at the end of the blade. This spike is set nearly at right angles to the edge of the knife and is used in picking up the beet from the ground. The person doing the topping is thus relieved of a large amount of stooping that would otherwise be necessary. The injury due to the use of this knife may be reduced by running the spike into the crown instead of the beet proper. The leaves and green portion of the crown should be removed together and at the location of the lower leaf scars. The crowns contain a comparatively large amount of mineral matter, and if not removed from the beet, this material becomes objectionable in the process of extracting and purifying the sugar. The crowns as well as the leaves make valuable feed for live stock and should be retained for feed in order that they may be used most economically.

The beets from several rows are thrown together in piles either before or after the tops are removed. If they are not hauled immediately they should be covered with tops to prevent evaporation and frost injury. Excessive evaporation

decreases the weight and adds to the difficulty of extracting the sugar.

Beet toppers both as separate machines and as inexpensive attachments to pullers are rapidly reaching perfection. At the present time there are several machines on the market that are doing very satisfactory and efficient work. When these toppers become sufficiently perfected to come into general use much of the tedious hand labor will be eliminated.

To market the crop the beets are loaded into wagons by hand or with a blunt tined fork. Time can be saved by loading small beets with a fork. The crop is hauled either directly to the factory or delivered at the railroad station and loaded into cars. The beets should be fairly free from dirt or excess portion of the root crown when delivered to the sugar company. Both dirt and excess portions of crown increase labor costs in handling the crop, and their weight is deducted from the gross weight of the crop when delivered.

BY-PRODUCTS

The by-products of the sugar beet crop are the tops and pulp. The tops are removed in the field and need not be taken from the farm. They consist of the leaves and root crowns and make a valuable feed for livestock. They contain a high per cent of moisture and are usually difficult to cure at the time of the year the beet crop is harvested. For this reason they are not suited for a commercial product and can be most economically used when fed on the farm on which they were produced.

It is common practice to feed the beet tops by pasturing the field with sheep or cattle. If the grower of the beet crop does not have sufficient live stock to utilize them, he usually can sell these tops to sheep men. The acre value of a field of beet tops varies with the yield per acre of the crop. One ton of marketable beets will produce about one-half ton of tops. Their feed value when pastured is often considered equal to that of the last crop of alfalfa which is not far enough advanced to cut as hay at the end of the growing season. If they are fed in the field little of the fertilizing elements of the crop will be lost as the resulting manure will be left on the land. Unless special care is taken

so that the field will not be pastured when too wet, many of the tops will be trampled into the ground. An excessive amount of soil adhering to the tops may be consumed while pasturing and will cause detrimental results to live stock. It is desirable to feed directly from the field as many of the tops as can be used, to a good advantage. Best results are not obtained and there is considerable danger to the animals fed when beet tops compose the entire ration. They are decidedly unsatisfactory as a feed for horses. Those tops which cannot be fed within a reasonable time may be stored and fed later. They can be stored to the best advantage when



Fig. 9. The Gleaners. Large flocks of sheep brought in from the summer range can be economically fed on a ration composed largely of alfalfa and beet tops pasture. It is a good feed and this is a profitable way to utilize it if fed with care. Feeding mouldy tops is dangerous, to the life of the animal but fresh tops fed to excess will also give unsatisfactory results.

placed in the silo. If an upright silo is not available for their storage, they may be placed to good advantage in a horizontal one. In either case layers of tops have often been alternated with thin layers of straw or the two materials have been mixed together. More straw should never be used than is absolutely necessary to absorb the excess moisture in the tops. A larger amount may prevent sufficient packing of the silage to exclude the air and a mouldy product results.

The horizontal silo is constructed by digging a trench three to six feet deep, ten to fifteen feet wide, and of sufficient length to accommodate the quantity of tops to be placed in storage. It is desirable to line the trench with straw to prevent wastage of the tops which would otherwise come in contact with the ground. The tops free from all soil that can be shaken off are thrown into this trench directly from the wagon and packed firmly by driving over them. After the tops are all placed in the trench they should be covered first with a thin layer of straw and then with either a layer of manure, or sugar beet pulp. The silo should not be disturbed for a period of several weeks after which feeding may commence. The trench may be opened at one end and the tops used up as rapidly as is consistent with good feeding practice. The proper storage of the tops and their value as a feed has not been definitely determined. This subject requires further investigation before details pertaining to their utilization can be authoratively presented.

The beet pulp is a more valuable by-product of the sugar beet crop than the tops. It conssts of the remainder of the beet after the sugar is extracted, and contains a high per cent of moisture in its original form. The wet pulp may be used immediately or it can be stored in a silo and kept indefinitely. Because of its bulkiness it is only practical to use the wet pulp within close range of the beet sugar factory.

The wet pulp may be dried out in which form it does not readily deteriorate and is used as a commercial product. Before feeding, it should be soaked in water until it absorbs two or three times its weight. Beet pulp when fed to live stock should be used with discretion and best results are obtained when used in such combination with other feeds as to furnish the succulence necessary for a good ration.

The value of sugar beet tops and beet pulp can be shown to advantage by comparing them with other standard feeds. The following table compiled from Feeds and Feeding by Henry and Morrison gives the total dry matter and the digestible crude protein, carbonhydrates and fat in 100 pounds of the material.

A field of beet leaves and tops when returned to the soil will have about the same beneficial effect on the physical

condition of the soil as a green manuring crop grown for that purpose. Much of this value is lost if the crop is fed to live stock even though the manure produced is returned to the land. About two-thirds of the organic matter of a feed is destroyed in the process of digestion. This organic matter if returned to the soil would tend to maintain the humus supply and since sandy soils are generally deficient in humus this means of utilizing the product should be thoroughly considered.

TABLE II.

Crop	Total dry matter in 100 lbs.	Digestible nutrients in 100 lbs.				
		Crude protein	Carbon-hydrates	Fat	Total	Nutritive ratio
Sugar beet tops	11.4	1.7	5.4	0.1	7.3	1:3.3
Sugar beet leaves	11.6	1.2	6.3	0.1	7.7	1:5.4
Corn fodder (kernels glazed)	26.2	1.1	15.8	0.4	17.8	1:15.2
Beet pulp (wet)	9.3	0.5	6.5	0.2	7.4	1:13.8
Beet pulp (dry)	91.8	4.6	65.2	0.8	71.6	1:14.6
Alfalfa hay	91.4	10.6	39.0	0.9	51.6	1:3.9

The following table also compiled from Henry and Morrison shows the fertilizing value of sugar beet by-products:

TABLE III.

Crop	Pounds in 1000 lbs. of material			
	Dry matter	Nitrogen	Phos. Acid	Potash
Beet pulp (wet)	9.3	1.4	0.4	0.7
Beet pulp (dry)	91.8	14.2	2.4	3.8
Leaves (in field)	11.6	3.0	1.2	5.5
Tops (in field)	11.4	4.2	1.0	6.4

LABOR

The work of preparing the seed bed and planting and cultivating a crop of sugar beets is of such a character that it may be handled by the help regularly employed on the

general farm. The blocking, thinning, weeding and harvesting require a great deal of extra labor. This labor is oftentimes hard to obtain, and difficult to employ economically since it is only used at specific times during the year.

Because of the lack of continuous work extra labor must be brought in for the busy season in sections where the farms are large and a high per cent of the land is devoted to beet growing. It has been a common practice to employ laborers on a contract basis to do this hand work at a fixed price per acre. They commence their work at the beginning of the growing season and remain until the crop is harvested, and must then find other employment for the remainder of the year. Often the entire family of these laborers work in the sugar beet fields. One advantage of this



Fig. 10. Work for Everybody. The work connected with sugar beets is such that much of the available family labor can be used at a profit.

type of labor is that they are willing to do the hand work that the general farmer dislikes. The disadvantage is the high cost that naturally results from employing more or less irresponsible labor for short periods. Improvements in machinery that make for the elimination of hand labor at only one season of the year will not solve the labor problem. In other words a satisfactory topper to entirely meet the de-

mands should be accompanied by suitable machinery for thinning.

If the area planted to sugar beets is comparatively small and is grown on the same farm in connection with other crops such as alfalfa, corn, and potatoes, the farmer and his family or the labor employed regularly can perform the hand work as well as the general field work. The permanency of the beet sugar industry is decidedly benefited by, and may eventually be dependent upon a fair acreage of sugar beets grown on nearly every farm instead of a large acreage on a few. The many small farms in the irrigated districts of this state should for this reason offer almost an ideal condition for the culture of this crop.

PLACE IN THE ROTATION

The place that a crop should have in a rotation is determined by its effect on every crop on the farm. Alfalfa, in many of the irrigated sections, has long been a favored crop. Large percentages of farm areas have been devoted to its production. It is commonly known, however, that one of the most important values of this crop lies especially in the benefit it has on the soil in preparing it for the cultivated crop that is to follow. The beneficial effect of alfalfa is based almost entirely on the fact that it keeps the soil well supplied with humus and nitrogen, and nitrogen is the limiting element of plant food in nearly all irrigated sections. It has also been found that alfalfa leaves the soil in nearly as good condition when it has been grown three or four years in succession as when grown for a much longer period.

The introduction of another cultivated crop like sugar beets into a rotation should reduce the number of years that alfalfa is grown continuously on the same field. Farmers will not be as strongly opposed to plowing up an alfalfa field if they can put another profitable crop in its place. On a farm where alfalfa, potatoes, sugar beets, corn, and some small grain are grown, the crops should follow each other in the order in which they are enumerated, and the grain crop should then be used as a nurse crop for alfalfa. The basis for this contention is that it allows sufficient diversification to make for greater stability in agriculture. From the system

of rotation recommended here, it should not be concluded that beets are not as successful when planted after alfalfa as when planted after potatoes. Following alfalfa with potatoes is more desirable because the largest yield of potatoes is produced when grown in this order, while sugar beets do well as a succeeding crop. The large root crowns of an old alfalfa field also interfere with the preparation of a good seed bed for sugar beets. The suggested rotation also provides for the better distribution of labor during the year. Planting time for beets comes soon after the seeding of small grains and just before the planting of corn, while the harvest of this crop is sufficiently late not to interfere with any crops commonly grown.

The sugar beet is a "strong feeder" and the charge is frequently made that it is hard on the land. This statement is, however, no more true for sugar beets than for any other crop producing the same yield under similar conditions. The beet is a good yielder and will often produce well on soil that is not in the highest state of fertility. The result of this is that the crop that succeeds beets is frequently not entirely satisfactory. This is due not so much to the fact that the beets take large amounts of fertility out of the soil, but mainly because there was a lack of available plant food to begin with, and the beet crop was able to utilize large amounts of what was available. Such a condition would indicate that an application of barnyard manure or commercial fertilizer which should be part of any good rotation system might well be applied to the succeeding crop.

Sugar beets should never succeed a potato crop that has suffered for want of plant food unless the ground is first properly fertilized. This fertilizer should consist of at least ten tons of barnyard manure per acre applied in the fall or early winter before plowing, or of an application of about three hundred pounds of a complete fertilizer high in nitrogen applied on the crop in the spring. Since sugar beets require a large amount of intensive labor the farmer cannot afford to use any field that does not give every assurance of success as indicated by the yield of the previous crop.

DISEASES

Sugar beets are comparatively free from diseases but the curly leaf, leaf spot, root rots, and damping off deserve consideration here.

The curly leaf of the beet wherever it does occur, should no doubt receive first consideration of all sugar beet diseases because of its destructiveness. It is hard to prevent or control, but fortunately it only occurs periodically. This disease was considered responsible for the partial failure of the 1918 beet crop in the Yakima Valley. The first symptom of the disease that appears in an absolutely definite form is the rough, angular or warty development of the veins on the under side of the leaf. This abnormal condition causes the leaf to curl up and knot-like swellings to occur at intervals on all veins and especially at the junctions. If the disease appears early in the season it has a dwarfing effect on the whole plant causing the leaves to turn in and fold up forming what resembles a loose head. Later the plant turns yellow in color, shrivels and dies. In extreme cases the stems and midribs of the plant may crack open allowing a dark sweet liquid to escape to the surface which upon evaporation leaves a deposit of sugar. Generally the root of the affected plant shows a large mass of fine rootlets made evident by the soil adhering to them. If the attack is mild or comes at a time when the beets are well established it may cause only the leaves to roll slightly with but little further injury. The disease develops best under hot dry conditions but may do considerable injury even under climatic conditions that are favorable for the best growth of the beet plant, while cold wet weather will almost always prevent its development. The disease rarely occurs two years in succession and it is quite common for it to almost completely destroy a crop one year and not be in evidence at all the next.

The conditions most favorable for the development of the disease are a large number of leaf hoppers, an early attack, hot weather and a field free from weeds. The opposite of these conditions together with frequent cultivation, early irrigation and shade or weeds are unfavorable for the disease. An attempt, however, should not be made to control the de-

velopment of the disease if the means are such as would interfere with the normal and economic growth of the cultivated plant. No satisfactory method of control is known at present with the exception that it is not advisable to thin the beets at the time when the hoppers appear.

The leaf spot though not found in this state at present is worthy of thorough consideration because of its wide distribution elsewhere and the consequent damage resulting therefrom. This is a fungus, the spores of which occur in small brown spots on the surface of the leaves. These spots

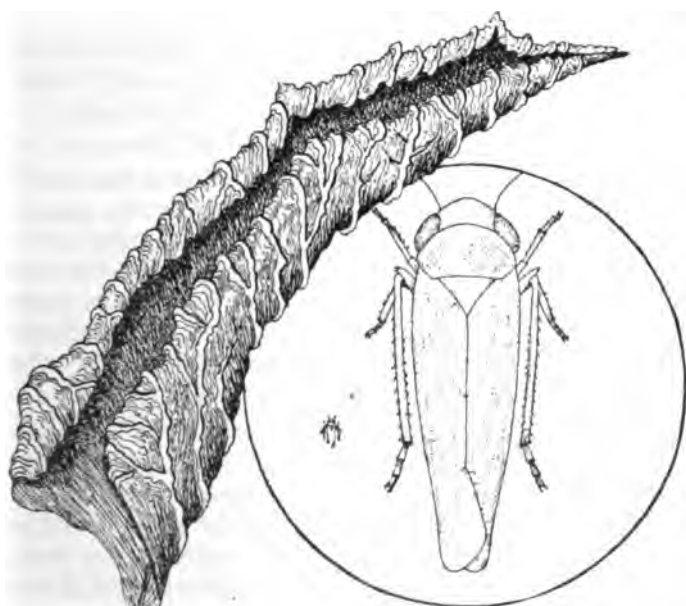


Fig. 11. The Curled Leaf of the Beet, Commonly Called "Curley Leaf" and the Sugar Beet Leaf Hopper Responsible for it. Utah Exp. Sta. Bul. No. 155.

later turn ash gray with a reddish purple margin. The spots are distributed over the leaf surface and may cover a large portion without any general discoloration until in time the leaf will blacken and dry up. When these outer leaves dry up and become curled and stand upright the plant continues to develop new leaves from the bud and the crown becomes

generally elongated. This has a serious effect on the root development and consequently results in a loss of sugar produced. The disease may be controlled by an early spraying with Bordeaux mixture but a rotation of crops is also very effective. Late planting is successful in combatting the disease but cannot be recommended because of its detrimental effect on the yield.

Root rots cause the growing root to turn brown and where conditions are favorable for its development all parts of the plant become affected and are gradually eliminated. The bacteria and fungi causing these diseases are common to many agricultural plants but will not readily develop on soils that give a strongly alkaline reaction. About the only means of controlling root rots is by planting the crop on clean soil and in the proper place in a rotation.

The scab on beets is the same disease as the scab found on potatoes. Its presence is made evident by the appearance of a sort of corky growth on the surface of the root. This disease retards the normal development of the beet and reduces the yield. It may exist in the soil for several years and consequently a system of rotation properly chosen should not permit this crop to follow immediately any scabby crop.

The damping off fungus is very destructive to young plants and develops best when there is a large moisture supply and a fairly warm temperature. Weak plants are more susceptible than those of more vigorous germination. It makes its attacks near the surface of the ground and causes the plant to droop and appear water soaked. The weakened stem finally causes the plant to fall prostrate and if it comes in contact with moist soil the fungus growth will rapidly distribute itself through the whole plant. There is no effective means of controlling or preventing this disease and an attack is generally fatal to the plant.

INSECTS

There are a great many insects that live on the sugar beet but most of them do very little injury. Those groups worthy of mention are the leaf hoppers, nematodes, the plant lice, flea beetles, plant bugs, leaf eating caterpillars, leaf min-

ers, web-worms, cut worms, woolly bears, wire worms, white grubs, blister bugs and grasshoppers.

Of all these the beet leaf hopper deserves separate consideration because it has been pretty generally proven that it is a carrier of the organism that produces the curly leaf disease. In fact all experimental work seems to indicate that sugar beets will not develop this disease unless their foliage has been punctured by this insect. The leaf hopper is a small greenish white insect whose color changes to a reddish tinge as it reaches maturity. It is only about one-eighth inch in length and comparatively slender. This is distinctly a desert insect and appears in great numbers quite early in the season soon after the beets are up. By puncturing the leaf and by apparently injecting into it a substance or organism it has the power to cause the development of curly leaf, the disease so fatal to the growth of beets.

Nematodes working in the soil attack the root system of the plant and have been decidedly destructive in sections of the country where beets have been grown continually on the same field. A proper system of rotation composed of such crops as are commonly grown in the irrigated sections of this state will not only check this pest but may even prevent it from getting a foothold.

The other insects enumerated above are of lesser importance and consequently are not given detailed consideration here.

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STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIRECTOR'S OFFICE

Twenty-Ninth Annual
Report

For the Year Ending June 30, 1919

BULLETIN No. 155
MARCH, 1920

All Bulletins of this Station are sent free to citizens of the State on
application to the Director

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C. E. Hill, B. S.*	Superintendent Waterville Branch Station
R. P. Bean, B. S.	Superintendent Washington Irrigation Station

*In cooperation with the United States Department of Agriculture.

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Pullman, Washington,
January 20, 1920.

Honorable Louis F. Hart, Governor,
Olympia, Wash.

Sir:—

I have the honor to transmit herewith a report of the activities of the Washington Agricultural Experiment Station from July 1, 1918, to June 30, 1919. For convenience in reporting results, some of the divisional summaries cover the period up to January 1, 1920. The context indicates where this is the case.

Very respectfully,
EDWARD C. JOHNSON,
Director.

Twenty-Ninth Annual Report, Washington Agricultural Experiment Station

DIRECTOR'S STATEMENT

Introduction. The activities of the Experiment Station staff thruout the period of the war were directed largely towards the stimulation of production as an essential war service. This was done primarily thru extension work in the field, thru bulletins and circulars and thru the general press. Investigational and experimental work, therefore, could not be emphasized as intensively as is desirable under more normal conditions. Most of the projects, however, were continued and considerable progress made. How to redirect the activities more fully to needed investigational and experimental work became the readjustment program on the signing of the armistice. The remainder of the fiscal year was devoted largely to a review of the investigational needs of the state, a readjustment of the funds and projects so as to meet these needs in so far as possible, a correlation of the work of the various divisions, increased emphasis on active projects and resumption of work on some of the projects that had lapsed. It was found advisable to continue in large measure the pre-war investigational program altho, in the light of new conditions, certain modifications and additions were made.

Additions and Changes. The organization of the Division of Farm Management in the Station and College to conduct investigations, especially in farm organization and in cost of production and to teach farm management to advanced students in the College of Agriculture, constitutes one of the more important additions of the year to the Station and College. This division should be given every possible support in order that it may cover the outstanding management and business problems of the principal farming sections of the state.

Another distinct step in advance was the beginning in May, 1919, of the development of the Irrigation Branch Station at Prosser for which an appropriation was made by the last legislature. This Station will give careful emphasis to the problems of irrigated Washington just as rapidly as its support will permit.

The goitre investigations, conducted at the temporary experiment station in the Methow Valley, were practically completed. Other pressing veterinary problems of the state will now receive attention.

Investigations in Cooperation with the U. S. Department of Agriculture. Investigations in cereals and forage crop production conducted in cooperation with the Office of Cereal Investigations and the Office of Forage Crop Investigations of the U. S. Department of Agriculture were continued at the Adams Branch Station at Lind and the Branch Station at Waterville. Cooperation with the Bureau of Entomology of the same Department in investigations of cranberry insects was continued at the temporary Station at Ilwaco.

An investigation of the wire worm in the wheat-growing area of Washington was undertaken cooperatively by this Station and the Bureau of Entomology, the work being done primarily at the Adams Branch Station and at the Central Station at the State College.

Cooperative work with the office of Horticultural Investigations of the U. S. Department of Agriculture relative to seed potato production was commenced.

Changes in the Staff. The following resignations went into effect: R. P. Bledsoe, Assistant Superintendent of the Waterville Experiment Station, August 16, 1918; Walter Garrison, Foreman at the Adams Branch Experiment Station, January 31, 1919; Asher Hobson, Director, Bureau of Farm Markets, April 1, 1919, and George Wehrwein, Assistant in Farm Markets, September 1, 1918.

The following appointments were made: Edward C. Johnson, Director, Washington Agricultural Experiment Sta-

tion, January 1, 1919; C. E. Hill, Assistant Superintendent, Waterville Branch Station, February 1, 1919; R. P. Bean, Superintendent of the Irrigation Branch Station, May 1, 1919; John W. Cochran, Foreman at the Waterville Branch Station, March 1, 1919; Harry L. Cole, Assistant Chemist of the Experiment Station, February 12, 1919; Milton Brandt, Assistant in Bacteriology, April 10, 1919; Chris Koch, Foreman at the Adams Branch Station, February 1, 1919.

H. M. Wanser was assigned as Assistant at the Adams Branch Station, April 1, 1919, his salary being paid by the U. S. Department of Agriculture.

The work of the various Divisions of the Experiment Station has been summarized and is reported by Divisions in the following pages.

New Legislation. A Feeding Stuffs Law and a Dairy Code enacted by the last legislature require that the necessary analytic work in connection with official samples submitted by the Commissioner of Agriculture shall be done by the Chemist of the Experiment Station, who is also State Chemist. An injunction by the court against the enforcement of the provision for a 10 per cent. limit of crude fiber in any commercial feed rendered the Feeding Stuffs Law ineffective for some months and therefore the number of samples submitted for analyses were limited. The decision of the Supreme Court, when made, upheld all provisions of the statute and the law is now in full force and effect. No special appropriation was made to the Experiment Station by the legislature for this work and it is handled out of the State College funds set aside for experiment station use.

Agricultural and vegetable seeds legislation was enacted which, similar to the provisions of the Feeding Stuffs Law and Dairy Code, requires that the analytic work for purity and germination of such seed samples as shall be collected by the Commissioner of Agriculture, his inspectors or assistants, shall be conducted by the Washington Experiment Station. No special appropriation to the Experiment Station for this work was made.

While the technical analytic work in connection with the regulatory work of the State Department of Agriculture can well be done in the laboratories of the Experiment Station and it is believed that such practice insures both accuracy and economy for the state, it would seem that the expense of such work should be borne by the State Department of Agriculture rather than by the Experiment Station and a definite fund set aside in its budget for this purpose.

An act establishing a Division of Apiculture in the State College of Washington for the purpose of regulating the importation, keeping and sale of bees, also was enacted by the legislature and an appropriation of \$4000 for the biennium made for the purpose of enforcing the act thru inspectors appointed by the State Entomologist, by and with the consent of the Dean of the College of Agriculture of the State College of Washington.

Funds were appropriated for use towards the completion of Wilson Hall and the Divisions of Chemistry, Soils and Plant Pathology will move in, as soon as the work is complete, vacating their present quarters in other buildings.

DIVISION OF ANIMAL HUSBANDRY

Howard Hackedorn, in Charge.

The system of farming in Eastern Washington is such that an annual legume crop is desirable. The production of peas for seed fulfills this requirement and has proved a profitable venture. For this reason there is considerable pea straw available for live stock feed. How this can best be utilized is one of the important questions in the mind of the farmer. A series of tests to obtain some information on the use of the pea straw, therefore, has been undertaken by the Division of Animal Husbandry.

The Value of Pea Straw as a Roughage for Lambs. In a test of the value of pea straw two lots of 6 lambs each were fed, Lot 1 receiving an average daily ration of grain,

1 lb. and alfalfa hay, 3.42 lbs., and Lot 2 receiving the same grain ration as Lot 1 but 3.49 lbs. of pea straw in place of alfalfa hay. This represented all the roughage the lambs would satisfactorily eat without undue waste. The lambs were put on the experiment on December 18 and continued until April 17, or a period of 120 days.

During this period the lambs receiving the alfalfa hay gained 43.70 lbs. and those receiving the pea straw, 30.77 lbs. The average weight of the fleeces of the former was 10.41 and of the latter, 10.17 lbs. With alfalfa hay costing \$25.00 per ton, pea straw \$10.00 and grain \$60.00 per ton, the lot receiving the alfalfa hay cost \$19.965 per 100 lbs. gain as compared with \$18.82 per 100 lbs. gain for the lambs receiving the pea straw.

The Value of Pea Straw as a Roughage for Wintering Pregnant Ewes. The breeding ewes of the College flock were used in this experiment. Two lots of 13 ewes each were given a ration consisting of grain and alfalfa hay (Lot 3) and grain and pea straw (Lot 4). Some ewes proved to be dry and for various causes others had to be taken out. Only those ewes that lambed were used in the final computations of the results. The average feed consumed was necessarily used. In Lot 3 nine ewes finished this test and eight ewes in Lot 4.

Ewes receiving the pea straw required .16 lbs. more grain per head per day than the ewes which received the alfalfa. The latter were fed $\frac{1}{2}$ lb. of grain per head per day. The two lots of ewes were approximately equal in other respects. The difference in the cost of wintering the breeding ewes was \$1.99 in favor of the ewes receiving the pea straw. The feed per head in the lot of ewes receiving the pea straw during an average feeding period of 80 days cost \$3.34, while that for the lot receiving alfalfa hay cost \$5.33. The prices of feed used in this calculation was \$25 for alfalfa hay, \$10 for pea straw, and \$60 for grain per ton.

Pea Straw as a Roughage for Ewes Suckling Lambs. In order to obtain more complete data as to the value of pea

straw as compared with alfalfa the two lots of breeding ewes were continued after lambing on the same rations which they were receiving before lambing. At the time the lambs were 60 days old the ewes were taken out of the experiment, each ewe and lamb being weighed individually at the end of the 30 and 60 day periods after the birth of the lamb. Seven ewes suckling nine lambs were used in each of the two lots. The lambs in the two lots made approximately the same gain and the ewes of both lots practically maintained their weight. However, it required an average of 1 lb. more of grain per ewe per day for the 60-day period to hold the ewes receiving pea straw up to the average of those receiving alfalfa hay. The average daily ration for the lot receiving alfalfa (Lot 3) was 1.9 lbs. of grain while that for the lot receiving the pea straw (Lot 4) was 2.93. Due to the heavier grain feeding required by the ewes in Lot 4, the cost of feeding the ewes from lambing time during the first 60 days of the suckling period was practically the same.

Forage Crops for Pork Production. In studies of the economic utilization of alfalfa and peas for the production of pork it was found that it would be more profitable with present hay prices to make one cutting of alfalfa before pasturing with hogs. This should be done a little earlier than the optimum time to cut alfalfa for hay, thus giving the second crop a chance to grow before the weather becomes too dry. The second crop can be utilized very satisfactorily by pigs at weaning time.

Pigs pastured on alfalfa without additional feed did not gain sufficiently to warrant feeding them in this manner.

Peas proved to be a very satisfactory pasture crop for hogs. The addition of a two per-cent. grain ration with this pasture did not prove profitable.

DIVISION OF BACTERIOLOGY

T. J. Murray, in Charge.

Legume Culture Work. The legume culture work was continued and is gaining in importance. In cooperation with

the Division of Farm Crops, inoculating material sufficient for 11,463.5 acres was furnished to the farmers from the Bacteriology Laboratory, as follows: peas, 6110 acres; alfalfa, 3506.5 acres; sweet clover, 528 acres; clover, 520 acres; beans, 508.5 acres; vetch, 447.5, and soy beans, 36 acres.

A Comparison of Different Inoculating Cultures. This project was undertaken with a view of determining, under field conditions, the relative efficiency of the cultures furnished by the Experiment Station and commercial cultures sold on the market. The cultures used were: 1. Inoculated sterilized sand; 2. Inoculated sterilized soil; 3. Field soil which was well inoculated; 4. A commercial culture on agar; 5. Standard experiment station culture on agar; 6. A commercial culture in soil; 7. A second commercial culture on agar.

The cultures used were for peas only. Eleven individuals volunteered to plant peas inoculated with these cultures in acre plots. Checks with no inoculation were also run. Careful work, however, was carried on only in four cases. Cultures Numbers 1 and 5 were very effective. The inoculated soil and field soil gave poor results. Fair results were obtained with the commercial culture. Laboratory work was carried out on all the cultures and all showed ability to inoculate peas. The number of bacteria also was determined. The cultures showed from 20 to 1000 bacteria per seed. This work was conducted in cooperation with the Department of Farm Crops.

Factors that Control the Infection of Legumes by Bacteria. Work was started with a view of determining the effect on inoculation of moisture, temperature, number of bacteria, the virulence of bacteria, the methods of inoculating and growing bacteria, and methods of applying bacteria to the seed. Only a little work was done on this project. It was found that inoculation took place in Palouse soil under laboratory conditions at between 12% and 26% moisture content.

Bovine Tubercle Bacillus. Believing that if the fatty substances in the tubercle bacillus could be removed in the process of cultivation by gradually replacing glycerine with urea, that a fat-free organism might be obtained and then a successful vaccine might be made with the fat-free organism a synthetic liquid culture medium was made by C. A. Magoon and the results reported in Bulletin No. 132, "Isolation and Cultivation of Bacterium Tuberculosis on a Synthetic Culture Medium." In addition, in his notes he states that he succeeded in obtaining fat-free tubercle bacilli. This work which was started in 1914 has been rechecked, using the synthetic solution as a basis. In no case were fat-free bacilli obtained. In addition when all the glycerine was replaced by urea, growth ceased. It is proposed to use other sources of carbon for the tubercle bacillus and if fat-free organisms cannot be obtained, to drop the work.

The Effect of Straw on the Soil. It has been observed that the addition of any considerable quantity of straw to the soils of Eastern Washington causes a decrease in the following crop yield. A study of the effect of straw in the soil was undertaken in cooperation with the Division of Soils with a view to determine the cause of the decrease in yield resulting from the application of straw and in the hope of devising, if possible, some method of returning humus to the soil without ill effects.

Results were obtained that indicate that the addition of straw of between .1% and .7% actually stimulates the formation of nitrates. When added in greater quantity, and thru to the end of 24 weeks, there is a loss in nitrates in every case. The greater the addition of straw, the greater the loss in nitrate formation. This work is being checked and will be continued to determine what are the ultimate results of straw on nitrification. Total nitrogen determinations show that, altho there is a loss in nitrates and nitrate formation, there is never any loss in total nitrogen. There is, on the other hand, a continual increase in nitrogen content. It is evident that while plant food in the form of nitrates is lost, it is not

permanently lost but probably is changed to protein nitrogen.

Bacterial counts were made on the soil under experimental conditions after 3, 6, 9, 12, 18, 24, 30, 36 and 42 week intervals. It was found that as the straw increases, the number of bacteria increases; with 5% straw, the count runs from 130,000,000 to 190,000,000 bacteria per gram at the end of 12 weeks. The present tendency is toward a reduction of these high counts. At the end of 36 and 42 weeks, with 5% straw there are about 50,000,000 bacteria per gram. The checks with no straw run between 1 and 3,000,000 bacteria per gram. It is evident that the straw acts as a stimulant to bacterial reproduction, serving perhaps as a source of energy. The bacteria in turn act on the nitrate nitrogen and probably throw off protein nitrogen.

Some work was done with nitrate bacteria. About eight strains were isolated. The effect of increasing amounts of pure cellulose in solution on these organisms was studied and there were no ill effects. It is apparent that cellulose has no inhibiting effect on the nitrifying bacteria. Work is in progress to determine the effect of cellulose of straw on these bacteria. Greenhouse work is in progress for testing the effect of straw on wheat growth and also the effect of growing legumes previous to the growth of wheat.

Miscellaneous Analysis. Forty samples of water were analyzed for the citizens of the state. Twenty samples of milk were analyzed and several examinations for diphtheria and for tuberculosis were made.

New Investigations Planned. In cooperation with the Department of Soils, it is planned to carry on some work on the nitrogen supply of semi-arid soils, with a view to improve agricultural methods in sub-humid sections.

DIVISION OF BOTANY

F. L. Pickett, in Charge.

Seed Analysis. A Seed Law for the purpose of regulating the sale of agricultural and vegetable seeds and for estab-

lishing grades and standards for such seeds was enacted by the last legislature. Its enforcement rests with the Commissioner of Agriculture, but the Washington State Experiment Station is required to make an analysis of all official samples collected by the Commissioner or his representatives and to report these analyses to the Commissioner and to the vendor or party interested. As a result the seed laboratory has required more attention than formerly. During the year, January 3, 1919, to December 31, 1919, 1232 samples of seed passed thru the seed laboratory and were analyzed. This direct help to the agriculture of the state has been further reinforced by the identification of weeds and native plants and by the information furnished for farmers. A full record of distribution data also has been kept.

Spraying for Weeds. Definite work was done in determining the effectiveness of different treatments for the eradication of the wild morning glory (*Convolvulus arvensis*). No funds were available from the Experiment Station for this work, but inasmuch as the work had been definitely planned, such expense as was necessary has been borne from Botany Department funds. The work extended thru the summer and included the use of three chemical sprays and a program of intensive cultivation. As sprays, copper sulphate, iron sulphate and sodium arsenite were used. The copper and iron sprays proved wholly inefficient if not entirely harmless, but the sodium arsenite gave promise of great usefulness. This must be tested at greater length. The cultivation program gave satisfactory results for this season, but must be continued thru a longer time before a true estimate of its value as a means of complete eradication can be given.

DIVISION OF CHEMISTRY

George A. Olson, in Charge

The work of the Division of Chemistry is divided between Experiment Station projects and analytical work in connection with the regulatory work of the State Department of

Agriculture. The new laws, which became operative in early July with reference to dairy products and feeding stuffs, require that the necessary analytical work be done by the chemist of the Experiment Station. This has increased the work of the Chemistry Division. As the number of official samples continues to increase, more help will be essential or there will be little or no time left for conducting research. As the investigational work is of primary importance, it should not be permitted to suffer.

Baking Qualities of Flour. Investigations relating to the "baking qualities of flours" have been emphasized during the year. The flours used were prepared in accordance with the United States Grain Corporation regulations.

Among the various determinations undertaken was a study of the nitrogen content, specific conductivity and viscosity of the carbon dioxide-free distilled water extract, 50% alcohol extract and 70% alcohol extract of flour. The specific conductivity and viscosity determinations also were made of the mineral matter contained in the various extracts mentioned.

The hydration capacities of the glutens and the specific conductivity of organic and inorganic acids in which glutens were immersed for different intervals of time and the nitrogen, ash, expansibility, and the acid hydrolysis of the glutens were studied.

The specific conductivity of the water extract of flours has the same order as the specific conductivity of 50% alcohol extract and 70% alcohol extract of flours. However, the specific conductivity of the 70% alcohol extract is less than that of the 50% alcohol extract which in turn is less than that observed in case of the water extract. The small margin of difference occurring in the specific conductivity of the various water extracts of flours in each of the series was due to the solubility of the substances which interfere with specific conductivity. At least, the order of the specific conductivity of the mineral content of the water-soluble extract is not the same as that observed in the water-soluble extract as a whole.

With regard to viscosity measurements, it was observed that the order of the 70% alcohol extract, while not exactly the same as in case of the 50% alcohol extract, nevertheless is similar especially if one considers that the differences occurring are within very narrow limits of variation. In the study of the hydration capacities of gluten, it was noted that the rate of the imbibition of water for the different glutes varied considerably. In general, it may be said that the order of specific conductivity also is the order of viscosity. Apparently the solubility of other substances than mineral matter influence the viscosities just as has been noted in case of the conductivity measurements.

Generally speaking, the volume per gram of expanded gluten was found to be in the same order as the conductivity measurements of the glutes which had been immersed in N-100 sulphuric acid. The conductivity measurement of the glutes immersed in N-100 lactic and citric acids were found to be in the inverse order of the volumes obtained per gram of expanded gluten.

In comparing the purity, percentage dry, expansion of baked amino-nitrogen content of glutes and the ratio of water-soluble nitrogen of flour to ammonia nitrogen of glutes, the following deductions have been made:

The purity of the glutes is inversely proportional to the expansion per gram of baked gluten.

The quantity of amino-nitrogen in the glutes appears to be in the order of the purity of the gluten.

The percentage of dry gluten and the ratio of the water soluble nitrogen of the flour to the ammonia nitrogen of the gluten appear to be in accord with each other but in the inverse order of the purity of the gluten.

Influence of Cultivation of Soil on Nitrogen Composition of Wheat. The five-year study of the influence of cultivation on the nitrogen composition of wheat has been completed.

Winter Wheats. The variations of nitrogen content of different wheats during the five-year period were as follows: Hybrid wheat No. 143 from 2.50% to 2.90%; Winter

Fife from 2.15% to 2.57%, and Turkey Red from 2.50% to 2.90% nitrogen content. The average annual variation in percentage of nitrogen of all varieties of wheat grown by farmers in the same locality ranged from 1.50 to 2.32.

Spring Wheats. In the cultivated plots, Hybrid No. 143 varied from 2.23% to 3.13% nitrogen and Bluestem from 2.37% to 2.83% in a four-year period, and in a three-year period Early Baart varied from 2.39% to 2.92% nitrogen content. The farmers' samples collected showed an average variation ranging from 1.73% to 2.5% of nitrogen.

Comparing the variations in nitrogen composition of the wheat with the variations of annual precipitation, the data show the tendency of the larger precipitations to be favorable to the production of higher nitrogen percentages in the winter wheat and lower precipitations to be favorable for higher percentages of nitrogen in the spring wheat. Comparing the composition of wheat on well-tilled and less well-tilled soil, the data show that good tillage favors a higher nitrogen content.

The data for the yields of wheat and the quantity of nitrogen that such wheats would remove are being computed and will be published as a separate paper.

Suspended Projects. Work has been temporarily discontinued on "The Function of Sulphur as Plant Food" and on "Cooperative Study of Methods of Analysis" with the Association of Official Agricultural Chemists and on "Relation of Soil Types to Composition of Wheat."

Service to Other Divisions. The Chemistry Division also functions as a service division for the other divisions of the Experiment Station. Milling tests, nitrogen determinations and gluten tests of 64 samples of wheat were made for the Farm Crops Division during the year and iodine determinations in enlarged and normal thyroid glands, and in samples of water, etc., were made for the Veterinary Division.

A two-years supply of samples relating to the function of sulphur as plant food material are still on hand to be analyzed as well as numerous miscellaneous samples. It is

hoped that this material can be analyzed at some opportune time in the year 1920, thus bringing all work up to date. Such a policy will make it possible for concentration upon the fundamental problems which are now being studied.

New Problems. The concluding of the project on the nitrogen composition of wheat should allow more time for work on the baking qualities of flour and the other suspended investigational work. Cooperation with the Bureau of Chemistry of the U. S. Department of Agriculture on official methods and with the various divisions of the station in connection with such projects as are now being investigated would be very desirable. The end of the study of the chemistry of wheat is by no means reached. Studies pertaining to the chemical changes in eggs during storage are of importance both practically and scientifically. Problems relating to the dairy and fruit industries should receive early attention. This will be given at the earliest opportunity and in proportion as help and funds for the work make expansion possible.

WORK OF THE STATE CHEMIST

George A. Olson, in Charge

The chemist of the Washington Agricultural Experiment Station is also State Chemist and has assisted the State Department of Agriculture in accordance with the provisions of the statutes.

Insecticides and Fungicides. Thirty-two samples of various insecticides and fungicides were analyzed. The arsenical and lime-sulphur preparations sold in the market were found to be above the guarantees of the manufacturers. However, there were two samples of spray material which were submitted which contained materials of questionable efficiency. One of the samples was composed of an alkali solution of Paris green and the other was a concoction of tar products and some nicotine, about one-half the bulk of which was made up of crystallized sodium sulphate.

Arsenic Content on Apples. Apples from typical sample boxes from the different orchard sections of the state were analyzed for the purpose of determining the quantity of arsenic contained on the apples, as the result of spraying with arsenate of lead. The analyses showed the arsenic content to vary as follows: 0.0006, 0.00098, 0.000427, 0.000729, 0.000747, and 0.00090 grams per apple.

Dairy Products. Beginning with the month of July, the Dairy Division has been submitting samples for analysis (132 in number) in accordance with the provision of Chapter 189 of 1919 legislature. Various samples of milk, butter and cheese were found to run below the standards.

Fertilizers. The analyses of 33 samples of fertilizers appeared to show that in a large percentage of cases the guaranteed compositions were a matter of form rather than actually showing the true composition of the fertilizer ingredients.

Foods. Analyses of 100 samples of food showed that the quality, generally considered, was very good. However, there were a few cases of evaporated milk and sausages containing artificial coloring and cereal which did not meet the requirements of the statutes.

Feeding Stuffs. A new feeding stuffs law was enacted by the last legislature which requires that the State Chemist shall analyze the samples of feeding stuffs collected and submitted by the inspectors. This law went into effect in the early part of July. From the analyses of 35 samples it has been noted that the feeding stuff situation has improved greatly when compared with former years.

DIVISION OF DAIRY HUSBANDRY

E. G. Woodward, in Charge

A Comparison of Corn Silage, Artichoke Silage and Sunflower Silage as Feeds for Milk Production. This investigation includes a study of the keeping quality, palatability and

nutritive value of different silages and their effect upon the flavor of the milk. The silage is now in the silo and will be fed during the winter.

The Cause of Difficult Churning. Difficult churning seems to be rather common in Washington. It is usually reported by persons having only one cow in milk after she has been in milk for a period of six months or longer. The cream froths and swells and will not "break" even when churning is continued for five or six hours. The milk also often develops a decidedly stale or bitter flavor within 48 hours after milking. Butter churned from the cream develops this stale flavor in about the same length of time.

From work done thus far, it seems that the trouble is not bacterial as it has not been possible to produce the condition by inoculation. Slight changes have been found in the chemical composition but no more than would naturally be expected in milk from a cow far along in lactation.

The cause of the trouble has not yet been determined. However, it has been found that pasteurization at a temperature of 145 degrees for 25 minutes will not only cause the cream to churn but when the cream is pasteurized while still fresh it keeps the bad flavor from developing and the quality of the butter is similar to that made from normal cream. Work on this problem will be continued when another cow producing such milk can be found in the college herd or nearby.

Fillers in the Manufacture of Ice Cream. As a result of a comparison of commercial ice cream powder, gelatin, gum tragacanth and corn starch for fillers in ice cream, it was found that the gelatin (4 oz. to mix for 10 gal.) was the most satisfactory as shown by a higher score on body, texture and keeping quality. This ice cream also repacked to better advantage than the others. The gelatin ice cream was the last to start melting when exposed to warm temperature although it melted completely and more rapidly when it started than the ice cream containing the other fillers. This quality was the chief point in favor of this cream. The

kind of filler did not influence the yield of ice cream. The work is being continued.

The Whipping of Cream. The influence of the richness of cream, age of cream, temperature of cream and stabilizers on the whipping of cream were studied. Contrary to popular opinion it was found that 30% cream whipped better than that containing either a higher or lower per cent of fat. The optimum temperature for whipping cream was between 50 and 70 degrees. The older the cream at the time of whipping the better it whips. This seems to be true up to the point of souring. The addition of one heaping teaspoon of sugar or 10 c. c. of condensed milk to a half pint of cream, before whipping was begun, hastened whipping and made a better finished product than where the pure cream was whipped. This work is being continued.

Sweet Clover for Pasture for Dairy Cows. A field of eight and one-half acres of sweet clover was seeded in the spring of 1919. During the late summer and fall, at a time when no growth was being made in other pastures, this sweet clover was thriving even when pastured heavily. For a time as many as 35 head of cattle were pasturing on it and as many as 16 head were on it until early fall.

More sweet clover will be seeded in the spring of 1920 and accurate notes will be kept as to time of pasturing and the number of cattle pastured.

"Sour Milk" Silage. A section of the silage in one of the large silos at the dairy barn was inoculated with a pure culture of *B. lactis acidii* grown in milk. Ten gallons of this culture was diluted with twenty gallons of water and was sprinkled evenly over the silage during the filling. A section 7 feet in depth was inoculated in one of the 14-foot silos at the dairy barn. This silage will be fed during the winter of 1919-20.

The Effect of Exercise and Feed Upon the Vitality and Breeding Ability of Bulls. The dairy herd bulls are being used in this investigation. Until a tread-mill was purchased the

bulls were given no special form of exercise. The Holstein bull was very slow in service, often requiring one-half hour to an hour to make a service. Neither was he a sure breeder. The same was true of the Jersey though he was not quite so slow in service as the Holstein.

Since exercising these bulls regularly one-half hour each day on the tread-mill the Holstein and Jersey have improved greatly in quickness of service and will serve cows in less than five minutes. The spermatozoa are practically 100 per cent alive when the semen is fresh and a considerable number are still alive after being kept in the laboratory for 30 hours. This investigation is being continued.

Investigation to Be Inaugurated. Studies in methods of of raising calves where only a limited amount of milk is available will be undertaken. These will include a comparison of skim milk, two commercial calf meals manufactured on the Pacific Coast and a home-mixed feed. Work will be started on this project in January, 1920.

Investigations Needed. Inasmuch as an increasing proportion of the meat in this country and especially in Washington will be supplied by dairy cattle, a detailed study as to the best means of utilizing the meat value of dairy calves should be undertaken. Should these calves be vealed? If not, how should they be developed and to what age?

Other investigations that should be conducted include the comparison of the successive cuttings of dry land and irrigated alfalfa as feeds for milk production; a study of final package pasteurization; and of the use of condensed milk in the market milk trade.

The Official Testing Work. The number of cows on test January 1, 1919, to December 1, 1919, is as follows: Guernsey 46, Holstein 305, Ayrshire 34, Jersey 244, and Shorthorn 3; or a total of 632.

The kind of tests made January 1, 1919, to December 1, 1919, are as follows: 2 day, 2933; 7 day, 256; 30 day, 30; and retests 35; or a total of 3254. This is an increase of 29.1% over 1918.

Number of breeders doing testing work, January 1, 1919, to December 1, 1919, is as follows: Ayrshire 4, Guernsey 16, Jersey 24, Holstein 36, Shorthorn 1, or a total of 81.

DIVISION OF ENTOMOLOGY AND ZOOLOGY

A. L. Melander, in Charge

Investigational work looking toward the control of insect pests has been actively pushed along several different lines, all of which are of much economic importance.

Cranberry Insects. The study of the insect pests of cranberries in Southwestern Washington, conducted in 1918 in cooperation with the Bureau of Entomology of the U. S. Department of Agriculture, was continued and concluded the past season. Extensive spraying experiments were carried on and the value of the nicotine-soap formula for use against the fireworm was determined. Conclusions from the two-year cooperative study will shortly be available for publication.

Wireworms. The wireworms and false wireworms destructive to wheat in the dry belt of the state have been the subject of a cooperative investigation inaugurated last April between this Station and the U. S. Bureau of Entomology. Much of the work was done at the Branch Experiment Station at Lind. Extensive tests of baits and poisons supplemented life history studies, and field cultural methods of control were carried on. The problem from its very nature will require several years before definite results can be announced since some of the species under investigation are biennial or possibly triennial.

Immunity of Insects to Sprays. In a continuation of this project identical solutions of standard insecticides were sprayed on San Jose scale at Clarkston, Walla Walla, Yakima, Tacoma and Wenatchee. Incidentally some of the newer sprays were used for checked comparisons. This work is being continued.

Codling Moth. In compliance with many requests the codling moth project, latent for several years, was reopened. Comparative studies of the effects of several insecticides of varying concentration were carried on at Cashmere, Opportunity and Moran. This work was in informal cooperation with the U. S. Bureau of Entomology and correlated with the Government's study of the codling moth at Yakima. Possibly the most important development of the year was the formulation of a method of expressing the exact value of a spray treatment in terms of index numbers.

Destructiveness of Columbia Ground Squirrels. In order to determine the actual destruction of wheat chargeable against ground squirrels a series of yards were fenced in, sown to wheat, and populated with squirrels. This controlled experiment showed that each squirrel in a wheat field costs the farmer from 35 to 50 pounds of wheat in reduced yield. As squirrels are the most abundant of our native animals, the importance of campaigns of control is apparent.

Bee Diseases. The formation of a State Division of Apiculture by the last legislature and the linking of its duties with the Entomologist, permits cooperative studies of bee diseases. A survey of the distribution of bee diseases in Washington was made and particular attention was given to the prevalence of bees dying immediately subsequent to orchard spraying.

Investigations Needed and Planned. It is planned to emphasize this season a study of arsenical spraying as a continuation and extension of the cooperative study of the codling moth. The objects in view include the following: (a) to determine the minimum concentration of arsenical required in orchard spraying; (b) to determine the minimum number of applications, and least amount of spray liquid required under Washington conditions; (c) to devise methods of better application and distribution of spray, by use of adhesives or suspension agents, or otherwise; (d) to determine the insecticidal value of various arsenicals; (e) to survey the methods of spraying at present employed by orchardists

with a view to correction of wrong practices; (f) to investigate the effects on the fruit and on the consumer of excessive quantities of spray; (g) to investigate the results to bees of arsenical spraying and of the drip on cover-crops; (h) to determine the extent of stigmonose caused by defecations of poisoned insects; (i) to investigate the effects on animals that feed on cover-crops receiving drip from excessive spraying.

In addition, the cooperative investigation of dry-land wireworm will not be allowed to lapse. The project on insect immunity to sprays should be continued. The testing of sprays as required by the law creating the State Insecticide Board should have increased attention. Two new pests, the apple leaf roller and the apple blister mite, have been particularly prevalent the past season, and should receive study as should likewise the subjects of woolly aphis, strawberry root weevil, red spider and oil spraying.

DIVISION OF FARM CROPS

E. G. Schafer, in Charge

Since the investigational work of the Division of Farm Crops deals largely with problems of the growing crop, the report here given covers the work accomplished with the last crop produced and harvested prior to June 30, 1919, or the crop grown in 1918. Where it was possible to include data from the 1919 harvest for drawing definite conclusions on the comparative value of wheat, oats and barley, such data were used.

The work of the year included investigations on different crop varieties; date of seeding fall wheat; inheritance of varietal characters of different cereal crops when their varieties are hybridized; silage crops; methods of seed production of alfalfa and clovers; value of a nurse crop; cultivation and rate of seeding wheat; cultural methods and crop rotations. Pure seed and bacterial cultures for legume inoculation have been distributed to farmers in different parts of the state, the latter by the Division of Bacteriology.

Field Crop Varieties. New varieties of cereals have been introduced into the cereal nursery where their yield and value have been compared, and the superior ones transferred to the field plots for further studies. Table I gives the 1918 average yield of the field and nursery and a five-year average of commercially grown wheats and hybrid wheats produced at the Washington Experiment Station.

TABLE I.
Acre Yield of Wheat Varieties in Bushels

Variety	Wash. No.	Average of 1918 Yield	Average of 1914-18 Yield
		Field & Nursery	Field & Nursery
Ruddy	598	22.07	44.2
Hybrid 128 ..	592	23.09	39.6
Triplet	597	19.18	37.5
Turkey Red ..	326	25.45	37.3
Little Club	500	18.50	33.9
Red Russian ..	270	14.40	33.6
Jones W. Fife	371	19.92	27.9
Forty Fold	351	15.47	26.3
Bluestem	362	22.89	38.9
Bluestem	362	22.98	38.9
Kustem	620	16.62	38.0
Red Chaff	420	23.92	37.1
Marquis	576	21.56	34.1
Baart	618	15.31	.....

This table shows that in a five-year average, Ruddy, a hybrid variety, produced the largest acre yield. Because of the inferior milling quality of Ruddy, Hybrid 128 is considered a more desirable winter wheat, especially for the Palouse region. Turkey Red, because of its comparatively high yield and good quality, and its hardy character should be an especially desirable wheat for districts of limited rainfall. Bluestem, because of its high yield and good quality, is considered one of the best spring wheats.

The oat varieties, Banner and Abundance, produced the highest yield in 1918 and for the average of a five-year period.

A winter barley known as Wisconsin, produced the highest yield in 1918 and for the average of a four-year period. California and Beldi, two of the coast barleys, produced the highest yields when seeded in the spring, both in 1918 and for the average of the five-year period 1914-1918.

The varietal studies with field peas show that the early, small seeded varieties produced a larger yield than the late varieties. The yield of 29.7 bushels per acre obtained from the variety Bangalia, for an average of the seven-year period, 1912 to 1918, emphasizes the importance of peas as a field crop. The Mexican Red produced the largest yield of beans, while none of the varieties of soy beans came to maturity.

Carrots produced a larger yield than any other kind of root crop. The yield in 1918 was 28.3 tons per acre, but only 17.07 tons for an average of three years.

Value of a Nurse Crop. The total yield of hay for the first year after seeding was greater when a nurse crop of wheat or barley was used in starting alfalfa.

The use of a nurse crop, however, reduces the chance of getting a stand of alfalfa and red clover. The growth of red clover is more seriously interfered with when seeded with a nurse crop than is the case with alfalfa.

Cultivation and Rate of Seeding Wheat. Cultivation increased the yield of winter wheat 6.8% and spring wheat 2.7% in 1918. The four-year average shows 15.1% increase in winter wheat and a decrease of 2.8% in spring wheat due to cultivation.

All of the six varieties used produced more grain on the plots seeded in rows 6 inches apart than on an equal area where the rows were 12 inches apart. The 12-inch seeding, in turn, produced more than the plots seeded in rows 18 inches apart.

Inheritance of Varietal Characters. The studies in smut resistance show that there are multiple factors for resistance in different wheat varieties which are inheritable independently, and are cumulative in effect. No correlations between resistance and other Mendelian factors have been established up to the present time. Turkey, Alaska, Florence, Kubanka and Marquis all contain elements of resistance to smut.

Beards are recessive to awnlessness in a simple Medelian ratio except in crosses where either Turkey or Red Russian enter in, as one of the parents, in which case there are only about one-half as many bearded segregates as in other crosses.

In several crosses of winter and spring wheats and spring barleys, the F₁ has ripened late and the F₂ has given a 1:2:1 ratio of normal spring plants, plants that ripened late and plants that did not head out.

The work this year proved that the plants that ripened late were heterozygous for the winter habit. This habit, probably, is a simple Mendelian major with minor variations as there are differences in the method of development of different winter wheats and barleys. Turkey and Hybrid 128 are both winter wheats but Turkey will joint in October when planted in April, while Hybrid 128 will not.

Marquis, Baart and Kubanka all produce a certain percentage of dwarf plants when crossed with certain other normal varieties. Part of the F₂'s indicated a unit character but the F₃'s in 1918 showed the impossibility of this interpretation as part of both normal and dwarf F₂ segregates were heterozygous for they produced both dwarf and normal plants in F₃. Dwarfness seems associated with late ripening and is probably linked with winter habit to some degree.

Crop Rotations. The crop rotation investigations were started on a field cropped uniformly for two years in preparation for the work. The field is divided into 48 one-twentieth acre plots. Twenty-two separate rotations are included in the experiment. The effect of different cropping

systems on the fertility of the soil is to be studied as well as the effect of different crops on succeeding crops.

Distribution of Seed. Pure seed of varieties of wheat, oats, barley, rye, corn, peas and artichokes, that have proved superior in the experimental fields, have been distributed to different parts of the state to which they were adapted. A total of 132,987 pounds of seed was sent out in 290 shipments and was distributed in 27 counties of the state.

Bacterial cultures for the inoculation of legumes have been distributed to farmers of the state in cooperation with the Division of Bacteriology. Sufficient bacterial cultures to inoculate seed for a total of 11463.5 acres have been supplied to 988 persons and have gone into every county in the state.

DIVISION OF FARM MANAGEMENT

George Severance, in Charge

Inasmuch as the Department of Farm Management was not established until May 1, 1919, there is very little to report. A Memorandum of Agreement for cooperation between the Office of Farm Management, U. S. Department of Agriculture, and the Washington Agricultural Experiment Station has been approved and Mr. S. O. Jayne has been assigned by the Office of Farm Management as full time representative from that office.

Projects Under Way. A cooperative project on cost of milk production and dairy farm organization has been approved, and from this work it is expected to develop a formula for determining the cost of milk production expressed in terms of feed and labor. A study will also be made of dairy farm organization for the purpose of determining the proper relationship between dairying and supplementary lines on dairy farms and such minor points as the relative economy of roots or silage for succulence, the growing or buying of hay, the feeding of concentrates on pasture.

As a basis for this work, arrangements have been made with dairy farmers at Lynden, Arlington, Oak Harbor,

Chimacum, Kent, Enumclaw, Chehalis, Montesano, Skamokawa, Prosser and Spokane to keep detailed records of the entire farm business including a daily record of labor distribution. The cooperators were selected by the county agents in the counties concerned and were visited by either Mr. Jayne or Mr. Severance and given instructions for keeping the records. The majority of them began keeping the records during October and November. It is planned to base all studies subsequent to March 1, 1920, on actual records rather than upon farm surveys. It is also planned to increase the number of cooperators if possible to 150 through the aid of the county agents, dairymen who are already keeping records and cow testing association testers. This division plans to utilize, as far as possible, county agents and others who may wish to work out theses along farm management lines for masters' degrees—agricultural teachers in the public schools of the state and leaders of any agricultural organizations that may become interested in the keeping of records. A number of such cooperators are actively at work.

DIVISION OF HORTICULTURE

O. M. Morris, in Charge

The investigational work in the Division of Horticulture dealt with eight projects, each of which is discussed independently.

Orchard Pollination. In this project a study was made of the relation of orchard pollination and the proper fertilization of apple blossoms to the June drop. It was found that practically all of the fruits that dropped before they had attained a diameter of three-fourths of an inch contained no normal seed, indicating that fertilization had not been effective. In the Jonathan apple, June drop fruits without regard to size, were seedless in the following proportions: 47% contained no normal seed; 27% contained normal seed in only one cell of the core; 18% contained normal seed in two

cells of the core; 6% contained normal seed in three cells of the core; none of the fruits contained normal seed in four or more cells of the core. These figures are the result of counts made of fruits collected from trees under which a crop of field peas was growing.

In counts made of fruits collected under trees that were standing in clean tilled land, 68% of the apples contained no normal seeds; 18% contained normal seeds in one cell of the core; 8% contained normal seed in two cells of the core; 5% contained normal seed in three cells of the core; and no fruits contained normal seed in four or five cells of the core. Other counts were made with similar results.

The difference in the amount of drop between land in peas and clean-tilled land indicates that soil moisture has some influence over June drop, but that in this case it was secondary to the influence of inefficient fertilization.

Mendel's Law in Blackberry and Raspberry Hybrids. This problem is difficult because the plants are pure species and do not have varietal lines of distinction. Furthermore, the varietal characteristics are not inheritable. The crosses necessarily made by the species are so violent that sterility of plants is common and differences of character are differences in degree and are not capable of direct contrast comparison. It was possible, however, to segregate a number of pairs of characters with a prospect of such crossing as would make possible statistical records of their appearance. The first pair of characteristics is the pubescence vs. the smooth surface of the fruits. The cross between the Loganberry and the Lucretia dewberry is being used for a study of this character. The second set of characters is the manner of separation of the drupes forming the fruit, from the core or receptacle. The Loganberry and the King raspberry cross promises to give a basis for a study of this character. The third characteristic is that of the vegetative reproduction of the plants. The red raspberry sends up sprouts from the roots. The black cap and purple cane raspberries produce sprouts only from the crown or base of the canes. The

cross between the Burkhard, a purple cane form, and the Marlboro red raspberry promises to furnish the basis for work on this characteristic.

Apple Rosette. Little work was done on this project. Some time was given to chemical analyses of badly rosetted twigs and their foliage, as compared to the normal twigs and their foliage. The work was only preliminary, but indicated a much higher ash and alkali content for the rosetted material than for the normal. An attempt to reproduce the rosette by feeding potted trees on strong alkali solutions has not been successful up to date. It is hoped, however, that another year may see some results in this work.

Orchard Cover Crops. Investigations in orchard cover crops constituted some of the more important work of the Division. Data were secured indicating that permanent cover crops such as alfalfa and clover may be established in orchards without checking the growth and production of the trees, provided a sufficient water supply is available and fertilizers carrying high nitrate content are added at the time or prior to the date of seeding of the cover crop. In the Wenatchee, Okanogan, Yakima, and Spokane Valleys the tendency of the growers has been to delay soil improvement work until the orchards show distinct need for it. The establishment of the cover crop under such conditions has usually resulted in a contest between the cover crop and the trees for plant food material and water and the result has been a retarding of the cover crop development and an apparent injury to the orchard trees.

Renovation of Prune Orchards. Soil improvement in prune orchards has been emphasized in this investigation. Nitrate fertilizers are the only ones that have made any distinct improvement in the orchards thus far studied. In an orchard at Felida, Washington, a certain brand of orchard dressing consisting of about 90% nitrate of soda, with less than 10% of animal by-products from the slaughter

house, gave an increased growth of 7.6% above the checked plots. Tankage and phosphate rock gave no increase in growth. Barnyard manure did the same thing. The results seem to indicate that decaying vegetation if abundantly applied will do more to improve the soil fertility in the orchards than any other material yet tested.

Apple Storage. In the tests made in the winter of 1918-1919 the fruit produced in the warmer valleys went down in storage before the material of the same valleys secured from the cooler and more elevated sections. Data relative to the condition of the fruit at the time of picking, differences in soil, etc., are not yet sufficiently comprehensive to make the work more than suggestive.

Seed Potato Production. The work on seed potato production is just organized and the first crop was produced in the season of 1919. Only one season's selection has been made and no results other than report of progress can be made at this time.

Fruit Evaporation and By-Products. The work on fruit evaporation and by-products in the year just closed was preliminary. In evaporation of apples no apparent favorable results were obtained by dipping the fruit in a solution before drying. The circulation of air in the drying kiln is one point in the commercial work that should be carefully investigated and tested. In work with the small laboratory evaporators it was found that added circulation with a fan greatly increased the rate of drying without increasing the quantity of heat generated. Tests were made with apple syrup to determine if the boiling point could be used as a gauge to determine when the material had been sufficiently concentrated to keep. These tests showed that at the elevation of Pullman, 2500 feet, material that was concentrated to a boiling point of 103 degrees C. was not uniformly satisfactory. Material that was concentrated at a boiling point of 104 degrees C. kept satisfactorily with only a few exceptions which possibly were due to errors in work.

Material that was concentrated at a boiling point of 105 degrees C. has kept in perfect condition without exception. Further work is needed, however, before this method can be advocated for public use.

Investigations Needed. There are many other problems affecting fruit and vegetable production in the state of Washington which should be given attention by the Division of Horticulture. Among these may be mentioned potato breeding and the production of seed potatoes—a project just initiated; the production of vegetable seeds, especially cabbage and cauliflower; the manufacture and storage of fruit products; the construction of fruit storage houses and fruit storage and warehouse management. Such problems as the retarding of the blossoming date of stone fruits, the growing of grapes, and the management of cranberry bogs also are deserving of attention.

DIVISION OF PLANT PATHOLOGY

F. D. Heald, in Charge

The Division of Plant Pathology for the year has confined its activities to six projects: Bunt or stinking smut of wheat; the *Rhizoctonia* disease of potato, tomato and other crops; fire blight of apple and pear; the Plant Disease Survey conducted in cooperation with the Plant Disease Survey of the U. S. Department of Agriculture; the covered smut of oats (*Ustilago levis*), and the covered smut of barley (*Ustilago hordei*).

Wheat Smut. The work on wheat smut has included both Fall and Spring plantings at the "Pathologium" as well as laboratory determinations and a number of experiments have been completed. These dealt with various phases of the smut problem, including seed treatment, the continuous use of formaldehyde solutions, relation of time of planting to per cent of smut in crop, comparative resistance of both winter and spring wheats, selection for smut resistance, a determination of the relation of spore load of the

seed to the per cent of smut appearing in the crop, effect of depth of planting and planting in trenches on the amount of smut, the effect of variation of spacing on the per cent of smut, the determination of seed injury and smut protection from farm seed treatments, and a comparison of the sack, open tank and Haskell methods of seed treatment.

Some of the results may be briefly summarized as follows:

1. A standard formaldehyde solution kept in a barrel in the open was used continuously through a period of three months without losing its effectiveness or injuring the treated seed.

2. Shallow planting gives less smut than deep planting; trenching less than level planting; wide spacing lessens the smut of resistant varieties, but has little effect on susceptible varieties.

3. The quantity of smut on seedlings in clean ground varies with the spore load, over 40,000 spores per grain being required to give maximum smutting. There is a minimum spore load which gives either a small per cent of smut or none at all. The accumulated data point to a multiple infection, rather than infection from a single spore.

4. Using two varieties of spring wheat, equally good protection was obtained by using the sack and open tank methods of seed treatment, but the Haskell method did not prove effective.

5. Of 116 varieties of winter wheat tested for smut resistance, none was smut-free, but certain strains of Turkey continued to show the least smut; of 86 spring varieties tested, six remained smut-free. Different strains of the same variety, from different regions, have shown wide variation in the quantity of smut in the crop.

The Rhizoctonia Disease The work on the Rhizoctonia diseases has been confined largely to experiments with tomatoes and potatoes. Tomato plants inoculated with pure cultures of Rhizoctonia from the potato gave 90% of blight

as compared with 58% in the uninoculated plants, but inoculation with infected potato peels did not increase the per cent of blight. The experiments with potato *Rhizoctonia* included tests of the standard seed treatment, varying both strength and time, a comparison of seed treatment versus seed selection, effect of spacing on the per cent of *Rhizoctonia*-infected tubers, the effect of Bordeaux as a stimulation spray, and the effect of different fertilizers. The following summary statements give some of the more important results:

1. The standard corrosive sublimate treatment of seed retards germination and lowers the yield if applied to sprouted seed stock, but increases the per cent of clean tubers.
2. Using a single lot of infected seed (three varieties), selected visibly clean, untreated seed has given higher yields of table stock than treated infected seed when treatment was delayed until the seed stock had sprouted.
3. Clean treated seed has given a lower yield than infected untreated seed, but the treatment very greatly increases the per cent of clean tubers.
4. None of the fertilizers used has increased the per cent of clean tubers when clean treated seed was used, but with untreated infected seed there has been a slight increase in the per cent of clean tubers over the unfertilized plots, sulphur giving the greatest increase.
5. Bordeaux spraying showed no material increase of yield or of clean tubers in our *Rhizoctonia* plots.
6. Continued field observations have shown that *Rhizoctonia* diseases are of increasing importance in the state, a number of new hosts being found. This trouble has proved to be a common cause of the dying out of strawberry beds, especially in Western Washington. A severe attack of onions, previously supposed to be immune to *Rhizoctonia*, has been brought to our attention (See Plant Disease Survey).

Plant Disease Survey. The Plant Disease Survey of the state has shown a number of troubles that were not previously

known to occur in Washington, and a number of others that are imperfectly known but have been increasing in importance. The following may be mentioned:

Loose smut of barley (*Ustilago nuda*), head smut of corn (*Sphacelotheca reiliana*), cranberry hypertrophy (*Exobasidium* sp.), die back of gooseberry and currant (*Botrytis* sp.), bacterial blight of magnolia blossoms (species undetermined), *Cytospora* canker of maple (*Cytospora* sp.), *Helminthosporium* disease of oats (*Helminthosporium avenae*), stem rust of oats (*Puccinia graminis*), *Rhizoctonia* disease of onions (*Rhizoctonia* sp.), neck rot of onions (*Botrytis alii*), leaf blight of *Ornithogallum* (*Heterosporium ornithogalli*), frost injury of raspberry followed by bacterial invasion, pine rust (*Peridermium flamentosum*), spinach rust (*Puccinia subnitens*), foot-rot of wheat, fungus uncertain, and frost injury to wheat when winter wheat was just coming into head.

A bulletin describing all the plant diseases of the state which have been studied during the seasons of 1915 to 1918 inclusive has been prepared and is ready for publication.

Oat Smut. The experiments with oat smut may be briefly summarized as follows:

1. The comparison of the sack, sprinkle and dry or Haskell methods of seed treatment gave the best results with the dry method.
2. The per cent of smut varies with the time of planting. Early planting gave a low per cent with a gradual increase to a maximum and thereafter a fluctuating decrease.
3. The tests of varieties for resistance have shown a number that remained entirely free from smut under conditions for producing maximum infection. Different strains of the same variety obtained from different regions have shown much variation in the per cent of smut when planted side by side.

Little work has been done on the fire blight project or on barley smut. Both should receive attention as soon as funds and assistance are available.

Investigations Needed. A number of very important disease problems have remained untouched. There has been much demand for more information on the cause and method of prevention of crown or collar rot of fruit trees, and this disease should be investigated as soon as possible. A new disease of wheat, the foot-rot, similar to, if not identical with the serious Australian "take-all," has been found in widely separated parts of the state. This disease is very imperfectly known, and would therefore justify special work on its etiology and prevention or control. A study of the comparative efficiency of dusting and spraying for the control of fruit diseases would meet a popular demand for information. There are many other disease problems of importance that need attention, such as: cranberry diseases, the *Helminthosporium* disease of oats, the *Rhynchosporium* disease of barley, the *Fusarium* rot of onions, and the rust of spinach.

DIVISION OF SOILS

F. J. Sievers, in Charge

Soil Fertility Investigations in Western Washington. The work on this project was carried on in cooperation with the County Agents. Many reports were received showing the benefit of specific fertilizer applications on definite soil types. While it has been impossible to draw fixed conclusions, it can be said that there are many soil types in Western Washington that are deficient in plant food. These soils respond to treatment varying all the way from the application of a single element to any combination of the four elements, nitrogen, potassium, phosphorous and calcium in the form of lime. Much work in the field as well as a definite system of mapping needs to be carried on before sufficient information is available to furnish the greatest service.

The Nitrogen Supply in Semi-Arid Soils. Plots of 1/20 acre were laid out on Wilson field at the College farm and definite plans made for field work at the branch stations at

Lind and Waterville. A considerable portion of the planned work is also under way in the plant house. Because the results up to date are still very closely associated with the soil moisture project, it was thought best, for the present at least, to report all work under soil moisture studies.

Soil Moisture Studies. This project received the most attention during the past year. The tillage plots were divided so that a crop could be obtained every year instead of every other year as formerly. One-half of each plot was seeded to spring wheat (Bluestem) and the other half was subjected to the various methods of summer fallow as originally planned. The plots seeded to spring wheat showed no variation in yield or nitrates in the soil. This is consistent with the findings of previous years in that the yield of grain is proportional to the percentage of nitrates in the soil.

The summer fallowed plots showed decided variations in moisture and nitrate content as affected by different times and methods of tillage. The results were more pronounced than ever in emphasizing the fact that the greatest quantity of available nitrogen is developed under those conditions where the tillage practiced retains the highest percentage of moisture in the surface foot of soil for the greatest length of time during the warm portion of the year. The most favorable condition resulted from early spring tillage followed by such subsequent tillage as was necessary to keep down the weeds.

The crop residue and nitrate plots on the College farm were favored by a good season and excellent results were obtained. Convincing evidence was obtained that nitrogen as well as moisture is one of the chief limiting factors in wheat production. Nitrogen fertilizers were used as a substitute for summer fallow with the result that increases in yield were obtained on all plots. The efficiency of the fertilizer, however, is affected by the time of application and by the kind of wheat on which it is used. Best results on spring wheat were obtained when the fertilizer was applied to the soil in the fall while on winter wheat best results

were obtained when the application was made in the spring. The average increase where the equivalent of 11 pounds of nitrogen was applied per acre was 4.65 bushels while where 22 pounds of nitrogen was applied the increase was 8.3 bushels.

On all plots where straw was applied there was a decrease in yield. This depressing effect of straw was in part overcome by supplementing the straw application with a nitrogen fertilizer. When all of the plots receiving straw are compared to those not so treated, the data show a decrease in yield of 3.63 bushels per acre caused by the straw.

Nitrate of soda showed a decidedly greater efficiency than ammonium sulphate as a fertilizer during the last season.

On plots where straw was applied and disked into the soil the yield per acre was 4.4 bushels greater than on plots where straw was applied without disking.

Detailed experimental work on the definite effect of moisture and nitrate on the wheat plant shows the following results:

The number of stools and the weight of the plant are in direct proportion to the quantity of available nitrogen in the soil at the time when stooling takes place.

The composition of young wheat plants of the same age is about the same under all soil conditions, but this composition varies as the plant develops and the nitrogen content of plants grown on soil rich in nitrogen is highest.

Nitrification takes place in Palouse silt loam very slowly when the moisture content of the soil is below 15%.

Crop Residue Work in Jars. That the organic matter in Palouse soil is rapidly being depleted is evidenced by the fact that results from determinations already show a loss of over 23% as a direct result of the summer fallow system for a period of 30 years.

Results obtained show that where straw was added to the soil the nitrate originally present almost immediately disappeared and although this condition was gradually over-

come, the subsequent nitrification was in inverse order to the quantity of straw applied.

The decrease in nitrates and the depressing effect of the straw was most pronounced when applied to soils already low in organic matter. Soils from the north hill slopes can withstand a heavier application of straw than those from the hill tops.

The depressing effect on the yield of an application of straw is most pronounced when such application is made shortly before the grain is seeded. Plowing under straw or even heavy stubble in the spring for spring wheat should be avoided. Better results are obtained when this stubble or straw has had more time to decay before the grain is seeded.

All data point conclusively to the fact that the difficulty of increasing the organic matter in the soil becomes increasingly greater as the natural supply in the soil becomes more and more depleted.

Soil Work on the Adams Branch Station, Lind, Wash.
In this section of the state where rainfall is decidedly limited, it was always supposed that moisture was the only limiting factor in crop production. Present results show, however, that nitrates are about as important as moisture and that both or either one separately may limit the yield. Where early summer fallow tillage is practiced and nitrification goes on very rapidly, moisture becomes the limiting factor, while in the ordinary or later summer fallow, where the period for nitrification is very short, nitrogen may become the limiting factor.

On all plots where early summer fallow was practiced and where the nitrates in the soil ran high, the least quantity of water was required to produce a pound of dry matter. On all plots irrespective of the tillage practiced, the moisture in the soil was exhausted at the end of the growing season but in the early tilled plots the soil still contained a large quantity of available nitrogen after the crop was mature.

The results from the application of crop residues and the growing of green manuring crops were not sufficiently conclusive to merit much consideration except that moisture is so decidedly the limiting factor either by indirectly supplying the needs of the growing plant or by indirectly supplying the needs for nitrification that any practice that decreases the moisture supply in the soil becomes a decided handicap. At present all practices that interfere with early summer fallow cannot be advocated except at a sacrifice in yield.

Miscellaneous Work in Soils. About 390 soil samples sent in by farmers were tested; 20 samples of lime and marl analyzed; and 75 soil samples tested for alkali. Two soil surveys on proposed irrigation projects were made and 18 press bulletins prepared.

Additional Investigations Needed. The work of all projects at present under way is incomplete in that it lacks in much detailed information necessary to fit the definite facts established into farm management practice. The stations at Pullman, Lind, Waterville and Prosser offer splendid opportunities to gain this information on definite soil types under different climatic conditions. Much information is still lacking on the following points which have a direct bearing on the permanency of agriculture: the part played by free nitrogen fixation; the possibilities of nitrogen fixation by legumes; the best use of barnyard manure and crop residues; the results of various rotation systems and the classification of soils from the standpoint of fertilizer requirements.

Soil Surveys in cooperation with the U. S. Department of Agriculture should be made of the more important agricultural areas of the state. Many other problems such as the best use of irrigation water for various crops, development and management of marsh soils, the improvement of soils in cut-over lands, the use of lime in Western Washington and land drainage in the Palouse and in irrigated Washington and Western Washington merit early attention.

DIVISION OF VETERINARY SCIENCE**J. W. Kalkus, in Charge****Goitre and Associated Conditions in Domestic Animals.**

The investigational work which has been conducted at the temporary experiment station in the Methow Valley since 1915 was this year completed and the experimental animals disposed of. The experiments conducted during the past year were chiefly in the form of further determination of the value of iodine in the prevention of goitre and hairlessness.

During the season of 1917-18, it was demonstrated that goitre and hairlessness in newborn angora kids could be absolutely prevented by the administration to pregnant females of iodine in various forms and by different methods. Four lots of angora does were used for the experiment. One lot was left untreated; one lot was treated by administration of 2 grains of potassium iodide daily to each animal; another by subcutaneous injection of 5 mils of a 10% solution of tincture of iodine once a week; and another by pouring 1 mil of tincture of iodine on the skin of each animal once a week. The treatment was continued throughout pregnancy and in every instance the young were normal at birth while the young of the untreated does were affected with goitre and hairlessness.

This type of work was continued during the season 1918-19 with the same animals. The purpose during the last season, however, was, first: to determine if a smaller quantity of iodine given less frequently would serve to prevent the disease; second: to verify further the efficacy of iodine in preventing goitre by administering it to those does which give birth to goitrous and hairless kids the previous season because of having been used as untreated checks, and, third: to determine if a sufficient quantity of iodine was stored in the body of a treated doe to supply the needs of the young in utero during the subsequent pregnancy without treatment.

Inasmuch as application of tincture of iodine to the skin gave just as good results as any other form of adminis-

tration and because this is the most practical method for ordinary use, it was resorted to entirely in this year's work. All of the treated does received one mil of tincture of iodine which was poured on the skin once every two weeks throughout pregnancy. In this way only half as much of the drug was used as during the previous gestation period. Results of this treatment were uniform and satisfactory; no indication of goitre or hairlessness was evident in the young. The results of some of the field experiments carried on in cooperation with stock owners indicate that in all probability even smaller doses of iodine and less frequent application will produce the desired effect. Mention will be made of these later.

It is quite evident that iodine administered to the does during one gestation period has a decided influence in preventing goitre in the young during the subsequent period. Treatment of those does, however, with the above dosage of iodine, which were previously untreated resulted in the prevention of goitre in the young. This further verifies the efficacy of iodine and also indicates that smaller doses are sufficient.

One lot of angora does, which were treated during the season of 1917-18, were left untreated during the following season. Two of the does in this lot gave birth to perfectly normal kids which indicates that treatment with iodine during the previous pregnancy effectively prevented goitre, but one doe gave birth to young which were affected with goitre and hairlessness. Apparently there is a great variation in individuals; some retaining a sufficient quantity of iodine to supply the needs of the young in a subsequent gestation period, while others must be treated during every pregnancy in order to supply those needs. Results show that it is unsafe to depend on previous treatment as a preventive of goitre and as the cost of treatment is negligible it is apparent that it should not be neglected.

Iodine also has been administered experimentally during the past two seasons to sheep in the same way as to goats. Sheep are not so susceptible to goitre as goats and the

young do not show the condition with such regularity and in as high percentage of cases. For this reason it has been impossible to control the results with these animals. In every instance, however, where iodine was administered to ewes during pregnancy the young showed no indication of goitre or hairlessness. This was true not only in the sheep used at the station, but the same results were experienced by practical stockmen who used the treatment according to direction.

Up to the present time it has not been possible to demonstrate, with suitable check experiments, the efficacy of iodine in the prevention of hairless pigs. An extensive study of this disease, including histological examination and chemical analyses of many thyroid glands, shows this condition to be the same as goitre affecting the other species of domestic animals. Experimental feeding has been conducted with 24 head of sows at the Methow Station during the past four seasons, for the purpose of determining the source of the cause of goitre. Results of these experiments were so variable that no definite conclusions could be deduced. Practically all of the experimental sows farrowed normal pigs and hence it was impossible to select individuals for use in iodine treatment.

The results of field experiments with sows conducted by this station, as well as by the Montana and Wisconsin Stations, seem to indicate that hairlessness among pigs can be prevented by administering iodine to pregnant sows.

In addition to the work done at the Methow Station, cooperative field experiments were conducted with practical stockmen. Iodine was furnished by the Experiment Station free of charge to all applicants who agreed to use it as prescribed and to report results of the treatment. During the past season 35 stockmen living in goitrous districts made application for the iodine treatment to be used on the following animals: 26 mares, 212 cows, 67 ewes and 45 sows. Twenty-four applicants made final reports of the results obtained in treating 20 mares, 149 cows, 67 ewes and 33 sows. Of these 11 mares, 137 cows, 66 ewes and 24 sows

dropped young. In every instance the young were born with no indication of goitre or hairlessness. All animals were treated by applying tincture of iodine on the skin once every two weeks. The dosage used for mares and cows was one teaspoonful and for smaller animals one-half teaspoonful. The number of applications varied from three to 20. Similar cooperative work is being conducted this year.

New Investigations Planned. Investigation of a disease known as "orchard horse disease," occurring in the irrigated orchard districts of Washington, is now being carried on.

Plans are also being made to investigate sheep diseases as soon as funds are available for the purpose. Each year large numbers of sheep are lost when bands are brought on-to summer range. It is believed by some that the losses are due to infection, while others attribute it to plant poisoning. An investigation of these losses should be conducted in order definitely to determine the cause and find a suitable method of prevention. It is hoped that some time can also be devoted by the Station Veterinarian to the investigation of red water in cattle, which is so common in many districts west of the Cascade Mountains.

Additional Investigations Needed. There are many other livestock disease problems in the state which are much in need of investigation. Among these may be named contagious abortion of cattle, walking disease and pernicious anaemia of horses, and poultry diseases.

THE ADAMS BRANCH EXPERIMENT STATION

M. A. McCall, in Charge

Investigational work on the Adams Station for this report year is still in the preliminary state. In establishing experimental work in a new locality this preliminary work is essential before undertaking fundamental investigations, in order to determine crops, varieties, and general practices which should be followed. Particularly is this true when

conditions in the locality where the work is being undertaken are such that practices followed or crops to be grown are widely different from those ordinarily followed or used.

Central Washington is devoted to an almost exclusive production of wheat, based on a summer fallow tillage system, and present knowledge is such that no suggestion for any marked change can be offered. Experimental work on the station is therefore devoted primarily to the investigation of wheat production problems, with side lines looking to the development of supplemental crops, and possible improvement in system.

The crop year of 1918, that covered by the period of this report, was extremely unfavorable for crop production. Moisture was very short, and results secured cannot therefore be accepted as applying in their entirety to more normal conditions. The value of the results secured lies largely in their application to conditions of extreme adversity.

Of the winter wheats under test, Turkey Red (Washington 326) proved most drouth resistant, and was best in yield and quality. Jones Fife, a popular variety of the district, was almost as good in yield, but not as good in quality.

Results of tests of depth of seeding for very late fall with winter wheat indicate the desirability of shallow seeding.

Depth of Seeding	Stand in Thousands per Acre	Yield per Acre	
		Bu. Grain	Lbs. Straw
1 inch	237	7.00	680
2½ inches	157	7.41	640
4 inches	171	7.33	530

The lighter stands gave slightly greater yields due to shortage of moisture, but the difference in stand secured indicates the shallow seeding as preferable in securing a stand.

Early Baart (Washington 618) was the best yielding variety of spring wheat grown on the station, averaging about 35% greater return than Bluestem, the one-time leading

spring wheat of this part of Central Washington. Yields secured from peas do not, however, compare very favorably with wheat. The best winter wheat gave a yield of 6.8 bushels per acre, and the best variety of field peas 5.3 bushels per acre. On a percentage basis these differences are considerable and under more normal conditions would give a still larger margin in favor of wheat.

The most important experiments on the station, those dealing with tillage methods for fallow and with soil problems, have not reached a stage justifying even preliminary report. In another season or two these experiments should be supplying very valuable information for the guidance of farm practice in the area served by this station.

THE WATERVILLE BRANCH STATION

C. E. Hill, in Charge

The Waterville Station now consists of 215 acres. The new farm of 160 acres leased in 1917 was given a permanent lay-out and cropped to experimental work for the first time this year. The investigations have been planned with a view of answering the needs of this section as completely as possible in determining the most profitable crops and methods of production and to save the farmer the expense of experimenting with new crops and methods which do not give profitable returns. Investigations with the following crops were conducted this year: small grains, field peas, corn, sorghum, sweet clover, vetch, soy beans, field beans, rape, kale, potatoes and sunflowers.

Small grains are the money crops and are also grown almost exclusively to supply hay and grain for livestock on the farms. A large amount of work was done on the station to determine the best varieties and mixtures of grains to grow for hay, pasture and seed, the most profitable methods of growing these crops, the best time of harvesting and the ratio of straw to grain. Beardless varieties which yielded the most thrashed grain were found to be the best varieties for forage. Several new varieties gave very

promising results. The highest yield of hay was obtained when harvested in the dough stage. Fall seeding gave better results than seeding in the spring. The practice of harrowing winter wheat in the spring, which is followed by most farmers, was not found to increase the yields on the station. Spring wheat grown in cultivated rows yielded higher than the same variety drilled in the usual way.

About eight acres were sown to different varieties of field peas. For such a dry year this crop made a very good showing and attracted considerable attention. It was found that peas must be sown early in the spring to obtain the best results. Peas sown on May 3 yielded 50% less than the same variety sown on April 15. The work with grain and forage crops will be continued, special emphasis being placed on the latter.

WASHINGTON IRRIGATION BRANCH STATION

R. P. Bean, in Charge

The Washington Irrigation Branch Station at Prosser is situated in the Prosser Irrigation District on the Sunnyside Reclamation Project. This district, located above the Sunnyside Canal, is watered by two pumping plants. The irrigation system for the district was constructed in 1918 and the pumping plants were equipped in May, 1919. The first delivery of water to the Station was on May 24th.

Prior to May 1, 1919, the citizens of Prosser had cleared the sage brush from 80 acres of the Station farm and had partially cleared 18 acres. The remaining 98 acres were cleared by contract after this date. Plowing was begun on May 1st and 37 acres were seeded to wheat in time to receive the first delivery of water on May 24th.

The development of land for crop proceeded as rapidly as practicable during the season. Approximately 10 acres were planted to potatoes and 15 to corn. Late in the summer 15 acres of leveled land were seeded to millet as a possible hay crop and to check excessive wind damage.

Development of the remaining raw land was so planned that a seeding program begun in August placed fields in crop as follows: 50 acres to alfalfa and winter wheat; 2 acres to sweet clover and rye; 26 acres of wheat stubble to alfalfa; 8 acres of corn stubble to alfalfa and wheat, and 7 acres of corn land to sweet clover. Except for an appreciable amount of wind damage the seeding went into the winter in fair condition. All fields that were leveled and equipped with flumes were put in crop.

There remains a total of 38 acres of raw land to plow and 70 acres to level, flume and put into a first crop. Of this amount approximately 7 acres are in the tract which will be largely devoted to Station buildings and this area will be seeded to alfalfa and rye. Another area of approximately 10 acres will be seeded to spring wheat and alfalfa. The remaining tract has been designated as the area for experimental work and will be handled in a manner to prepare for that purpose.

A beginning was made in the potato experimental work by planting, under the direction of the Division of Horticulture of the Experiment Station, Netted Gem seed potatoes obtained from 11 seed-producing districts ranging from Minnesota to the Coast. Because potatoes are a major crop for Irrigated Washington there is need for extensive potato experiments. The problem of economically securing seed capable of maximum production is second only to cultural and crop rotation problems.

Both alfalfa and winter grain variety tests were begun this season. Grimm, Peruvian, Turkestan, common seed grown in Kansas and in Dakota and Canadian Variegated alfalfa were seeded in plats. Hybrid 128, Jenkins Club, Jones Winter Fife, Marquis, Bluestem, and Dicklow wheats, White Winter barley and Winter rye (Minn. No. 2) were seeded in plats in duplicate.

Four large three-year-old mules, a team of heavy grade Percheron geldings three and four years old, and a light horse four years old were purchased for the Station this

season. Pending the drilling of a well, domestic water is hauled from a neighboring well and stock water is secured from the Sunnyside canal and from a seepage spring.

A well and adequate water storage are among the most needed improvements. In fact these would have been secured had a drilling machine been available prior to this time. Adequate barns will be required when the number of livestock on the Station is increased. The construction of one or more additional cottages as circumstances warrant will aid materially in securing satisfactory farm help.

Careful records of the cost of development of the land in making it ready for crops have been kept and will serve as a guide for new settlers. The entire farm is being developed and essential buildings constructed in order that the problems peculiar to irrigation farming in Washington state may be vigorously attacked.

THE OFFICE OF FARM MARKETS

Joseph Passonneau, in Charge

The Office of Farm Markets was created by an act of the State Legislature during its session of 1917. This law provided an appropriation of \$15,000 for the biennium and placed the office under the direction of the State Experiment Station by providing that the "director of markets shall be appointed by the director of the Agricultural Experiment Station of the State College of Washington by and with the approval of the governor."

The legislature of 1919 increased the biennial appropriation for the office of \$20,000. The expenditures for the year ending June 30, 1919, were \$9,101.99.

The function of the office as provided by law and carried out by the Director of Markets falls under four general heads: Market News, Assistance in Organization of Cooperative Societies of sellers and buyers, Research in Marketing and General Extension Work.

Instead of creating new machinery for carrying on the work in these different fields, arrangements have been made to work in cooperation with the Agricultural Extension Department, the Federal Bureau of Markets and the Department of Agriculture of the state. Consequently the work of organizing the cooperative associations as well as work in general extension has been done in cooperation with the County Agents and other workers of the Extension Service. The work in research is done in joint activity with the Experiment Station and with the College of Agriculture.

The Director of Markets is also employed as Agent in Marketing by the Federal Bureau of Markets, so that a close cooperative relationship exists between the office and the Bureau. There has been received from the Bureau of Markets, therefore, much timely information regarding marketing matters. Further, the Bureau contributes \$2000 annually to the work of the office. In addition, as Agent in Marketing, the Director has the privilege of using the frank.

In the work of Market News, the office publishes a Monthly Exchange Bulletin. This bulletin contains listings of different farm commodities for sale. From the beginning, this publication has met with favor and its popularity has continued to increase. Many sales are reported as being effected through listings in this bulletin. The bulletin also contains different topics of information regarding marketing. In connection with this may be mentioned the publication at the opening of the marketing season, touching upon the supply and demand of particular products and giving their probable current yields. The yields in other northwest states and in the United States as a whole are also included. Figures showing these yields are tabulated and calculations made with the yields during the previous five or six years for each particular locality. The prices of these commodities as received by farmers at particular dates each year are also given.

It is believed that with data at hand upon the supplies as related to prices during previous years, farmers should be in a good position to judge the condition of the market.

Assistance in organizing cooperative associations has been given to a large extent by conferences and meetings arranged through the County Agents. During the fiscal year ending June 30, 1919, seven such associations were organized.

For the coming fiscal year one representative of the office will be assigned to the work of marketing research. During the year 1918 the office prepared its first bulletin entitled, "Public Markets in the State of Washington." The data contained in this bulletin were obtained by correspondence with city officials, patrons of the Public Markets and farmers, and by personal visits to all public markets of the state, where farmers making use of the markets were personally interviewed.

The conclusions drawn by the office from the study of public marketing methods can be summarized as follows: (1) The extent to which farm products will be marketed through public markets will always be limited; (2) only the producers living within a limited radius of the city can make use of such markets; (3) it is not likely that products other than those included as perishables or semi-perishables will ever be offered on the public markets; (4) the costs of selling in this way are found to be excessive.

As an example of this, twenty per cent of the farmers interviewed sold less than ten dollars' worth of produce a day. Fifty-six per cent of them had an average sale of from ten to twenty dollars per day, and only twenty-four per cent sold more than twenty dollars' worth per day.

In addition to the above, representatives of the office have done more or less work in general extension—such as addressing farmers' meetings on different marketing subjects, including conferences and meetings held for the purpose of advising concerning the establishment of cooperative associations and meetings and conferences in connection with general extension work. During the past year 148 such conferences have been held and fifty-one farmers' meetings have been addressed.

PUBLICATIONS.

The following publications were prepared by members of the Experiment Station staff and published during the year:

GENERAL BULLETINS.

151. The Wind Dissemination of the Spores of Bunt or Stinking Smut of Wheat, by F. D. Heald and D. C. George.
153. Twenty-eighth Annual Report.
154. Sugar Beets Under Irrigation in Washington, by F. J. Siovers and E. G. Schafer.

POPULAR BULLETINS.

115. The Stinking Smut of Wheat, by F. D. Heald.
116. Two Important Varieties of Winter Wheat, by E. F. Gaines.

The following Extension publications were prepared by members of the Experiment Station Staff:

BULLETINS.

47. One Man Rack, by J. P. Fairbank.
49. Pruning Stone Fruit Trees, by O. M. Morris.
50. Pruning Apple and Pear Trees, by O. M. Morris.
51. Docking and Castrating Lambs, by Howard Hackedorn and C. E. Howell.
52. Growing Alfalfa Without Irrigation, by Geo. Severance.
53. Clover in the Palouse Country, by Geo. Severance.
54. Spraying for the Codling Moth, by A. L. Melander.
55. Essentials of Field Pea Production, by E. G. Schafer.
56. Corn Production in Washington, by E. G. Schafer.

ENTOMOLOGY CIRCULARS, by Members of the Division of Entomology.

8. Destroying Wasps and Hornets.
9. Leaf Hoppers of the Apple.
10. General Information About Bees.
11. Suggestions to Beekeepers.
12. Spring Management.
13. Consider the Bees When Spraying.
14. Lady-Beetles Versus Aphids.
15. Dry Lime Sulphur.
16. Oil Sprays for Dormant Use.
17. Swarming.
18. Queens Marketing.
19. The Bee Inspection Law.

FINANCIAL STATEMENT

WASHINGTON AGRICULTURAL EXPERIMENT STATION

in account with

THE UNITED STATES APPROPRIATIONS, 1918-1919

	Dr.	Hatch	Adams
Receipts from the Treasurer of the United States, as per appropriations for fiscal year ended June 30, 1919, under acts of Congress ap- proved March 2, 1887 (Hatch Fund), and March 16, 1906 (Adams Fund).....			
		\$15,000.00	\$15,000.00
 Cr. Abstract			
Salaries	1	8,482.46	11,433.04
Labor	2	3,478.94	2,134.88
Publications	3	698.80	.....
Postage and stationery.....	4	247.41	63.37
Freight and express.....	5	.....	10.34
Heat, light, water and power.....	6	7.25	.....
Chemicals and Laboratory supplies.....	7	179.25	309.96
Seeds, plants and sundry supplies.....	8	527.61	272.78
Fertilizers	9	21.00	8.23
Feeding stuffs	10	67.85	6.50
Library	11	.....	.....
Tools, machinery and appliances.....	12	267.39	109.62
Furniture and fixtures.....	13	85.94	.....
Scientific apparatus and specimens.....	14	636.96	329.33
Live stock	15	.....	9.00
Traveling expenses	16	252.14	312.95
Contingent expenses	17	35.00	.....
Buildings and land.....	18	12.00	.....
Total		\$15,000.00	\$15,000.00

FINANCIAL STATEMENT

State Funds Expended on Main Station and All Branch Stations.
(Excepting the Western Washington Station.)

April 1, 1918, to March 31, 1919.

Dr.	State Approp- riations	Indi- viduals	Sales	Total
To balance on hand.....	\$.....	\$ 63.57	\$1,295.60	\$ 1,359.17
Receipts from other sources than the U. S. for the year ended	18,623.94	.....	8,275.30	26,899.24
Total	\$18,623.94	\$ 63.57	\$9,570.90	\$28,258.41
Cr.				
Salary	\$ 3,991.16	\$ 63.57	\$ 599.75	\$ 4,654.48
Labor	7,100.89	.....	2,780.89	9,881.78
Publications .....	.....	.....	419.57	419.57
Postage and stationery.....	446.28	.....	530.58	976.86
Freight and express.....	315.69	.....	86.18	401.87
Heat, light, water and power	69.70	.....	26.83	96.53
Chemicals and Lab. supplies....	385.19	.....	123.76	508.95
Seeds, plants and sundry sup- plies	812.39	.....	1,205.66	2,018.05
Fertilizers	54.80	.....	.....	54.80
Feeding stuffs	2,087.82	.....	628.08	2,715.70
Library	104.40	.....	73.78	178.18
Tools, machinery and appli- ances	877.15	.....	620.83	1,497.98
Furniture and fixtures.....	516.14	.....	207.56	723.70
Scientific apparatus and speci- mens	274.50	.....	262.93	537.43
Livestock .....	.....	.....	.....	.....
Traveling expenses	899.13	.....	608.07	1,507.20
Contingent expenses .....	.....	.....	30.15	30.15
Buildings and land.....	688.90	.....	309.92	998.82
Balance .....	.....	.....	1,056.36	1,056.36
Total	\$18,623.94	\$ 63.57	\$9,570.90	\$28,258.41
Special appropriation for the Washington Irrigation Branch Station. Prosser, Wash., for the biennium April 30, 1919, to March 31, 1921.....				\$35,000.00-
Expenditures, April 1, 1919, to June 30, 1919.....				5,658.41

FINANCIAL REPORT

Western Washington Station.*

April 1, 1918, to March 31, 1919.

Dr.	State Appropriations	Sales	Total
To balance on hand.....	\$.....	\$ 4,043.29	\$ 4,043.29
Receipts from other sources than the U. S. for the year ended.....	28,629.71	15,566.60	44,196.31
	\$28,629.71	\$19,609.89	\$48,239.60
Cr.			
Salary	\$14,320.55	\$ 150.00	\$14,470.55
Labor	8,916.77	916.72	9,833.49
Publications	3,419.68	924.81	4,344.49
Postage and stationery.....	176.57	345.75	522.32
Freight and express.....	44.04	152.52	196.56
Heat, light, water and power.....	184.49	384.89	569.38
Chemical and Lab. supplies.....	.....	.....	.....
Seeds, plants and sundry supplies.....	374.14	1,856.21	2,230.35
Fertilizers .....	.....	51.38	51.38
Feeding stuffs	723.68	6,471.89	7,195.57
Library	1.00	.....	1.00
Tools, machinery and appliances.....	30.25	98.00	128.25
Furniture and fixtures.....	33.26	57.11	90.37
Scientific apparatus and specimens.....	.....	.....	.....
Live stock .....	.....	175.00	175.00
Traveling expenses	245.88	723.93	969.81
Contingent expenses .....	.....	.....	.....
Buildings and land.....	159.40	2,520.77	2,680.17
Balance .....	.....	4,780.91	4,780.91
	\$28,629.71	\$19,609.89	\$48,239.60

*The report of the work of the Western Washington Station, which was operated independently, is not included in this report.

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STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISION OF VETERINARY SCIENCE

A Study of Goitre and Associated
Conditions in Domestic
Animals

By
J. W. KALKUS

BULLETIN No. 156
JULY, 1920

All Bulletins of this Station are sent free to citizens of the State on
application to the Director

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*In co-operation with the United States Department of Agriculture.

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A Study of Goitre and Associated Conditions in Domestic Animals

INTRODUCTION

In 1915, this station undertook to investigate a series of diseases which seemed to be confined to certain restricted areas in the State and were apparently causing considerable loss among the various species of domestic animals. Although occasional reports of these conditions were received prior to this time, no systematic study was undertaken until attention was called to the fact that the trouble was apparently on the increase and becoming quite serious.

These conditions are variously designated by stockmen as "big neck" in newborn calves, "weakness" in newborn foals (weak colts), "hairless pigs" or "hairlessness" in newborn pigs, "weak lambs" or "weakness" and "big neck" in newborn lambs and "big neck" and "hairlessness" in newborn goats.

It is the object of the author to discuss these conditions as they occur in various domestic animals in Washington, together with a report of the results thus far obtained from experimental work. No attempt will be made to review the literature of other investigators, or to append a complete bibliography, but all the available literature on the subject has been freely consulted.

No attempt has been made to ascertain the exact distribution of the conditions under consideration. Our work has been confined largely to a study of affected animals. Our investigation, however, has been carried on in an area where goitre is very prevalent. Present knowledge indicates that the malady is most frequently found east of the Cascade Mountains along the valleys of the Wenatchee, Entiat, and Methow rivers, and on the banks of Lake Chelan. These are all mountainous regions, and the animal diseases referred to are found in the narrow valleys on both sides of the streams. Cases also have been reported from other sections along the

Columbia river on its west bank, extending from the source to the mouth. That the trouble is not confined to the west bank of the Columbia is indicated by reports of cases from Stevens and Spokane counties.

In June, 1915, the author had an opportunity to make a preliminary survey of the Methow valley in Okanogan county, where the diseases are especially prevalent and where a temporary experiment station was subsequently established. This trip was made in company with Dr. Carl Tenbroeck of the Rockefeller Institute for animal research, for the purpose of making a study of these diseases as they occur in various domestic animals. Because of the variation in the clinical aspect of the conditions in the different species of animals, the following pages will be devoted to a detailed discussion of the diseases as they occur in various species.

NATURE OF THE DISEASE

Although the conditions under consideration manifest themselves in slightly different forms in different species of domestic animals, the fact that they occur in the same locality at once indicates the probability of a common origin and similar nature.

During the preliminary investigation, an opportunity was afforded to make a careful examination of affected colts, calves, pigs, goats, and chickens. Results of this study indicated that in all probability the conditions were due to a common cause which manifested itself by certain changes in the structure of the thyroid glands. This was true with one exception. The thyroids of the first hairless pigs examined did not show this change, and it was thought that there was a possibility of the condition being of a different nature. Subsequent examination of thyroid glands of other hairless pigs, however, showed that the thyroid change occurred in the majority of cases. Up to the present time, over one hundred thyroid glands of the different species of affected animals have been examined microscopically and chemically, and the relationship between these various conditions established beyond a doubt. The microscopic study reveals that all spe-

cies of affected newborn animals have the so-called "hyperplastic goitre." The hyperplasia may vary somewhat in different individuals of all species as will be seen by referring to the illustrations, but the one outstanding feature is shown in the persistent absence of colloid, either in whole or in part, and the increase in cells. This latter may occur in various ways and will be considered more in detail under "Microscopic Study of Thyroids." Similar changes also occur in the enlarged thyroids of adult animals, but it is impossible to say whether or not this occurs in all adult animals that give birth to goitrous young. In many cases such adults have thyroids of apparently normal size, and no study has been made of such glands.

HORSES

No attempt has been made to determine the exact percentage of affected* horses in the goitrous districts,† but careful observation indicates that from 30 to 50 per cent of all adult horses have visibly enlarged thyroid glands. Examination of the thyroids in living animals also shows that in many cases where enlargement can not be seen, the thyroids are larger than normal. It is sometimes difficult to determine clinically, even by one who is experienced, the difference between a normal sized thyroid and one that is slightly enlarged; but it is probable that microscopic and chemical examination of many glands, especially those of mares which gave birth to affected foals, would show the same changes, possibly to a lesser degree than are seen in greatly enlarged glands. Unfortunately, an opportunity for detailed study of thyroids from many adult horses in a goitrous district has not been afforded. Although a large percentage of adult horses in these districts are affected with enlarged thyroids, these animals do not seem to be inconvenienced in any way as far as their general health is concerned. They seem to be normal in every other respect,

*The term "affected" as used throughout this bulletin refers to goitre as it occurs in the different species of domestic animals under discussion.

†"Goitrous District," as used here, refers to the areas in the state where goitre is prevalent.

and the only complaint made by owners is that the swelling is unsightly. It is commonly believed that the enlargement disappears within a few months time following the external application of tincture of iodine. Statements made by stockmen indicate that goitre in horses manifests itself within one year or more from the time they are brought to these goitrous districts and given local feed and water.

Although goitre does not seem to cause any serious harm to adult horses, it is extremely fatal to newborn foals. It is variously estimated by stockmen that from 75 to 90 per cent of the colts in some of these goitrous districts are affected with the trouble and that 95 per cent of such animals are either stillborn or die after two or three days. The remaining five per cent never make a perfect recovery, a fact which has been confirmed by careful observation.

According to stockmen who have had experience with the trouble, the gestation period of most mares which give birth to so-called "weak colts" is twelve months and in some instances, thirteen months. Our records show a gestation period of eleven months and twenty days in one case, and some report an occasional birth at eleven months. The majority of reports, however, indicate that the mares run overtime.

There is an unverified opinion that affected foals are oversized, but the fact that goitrous mares have no more than ordinary trouble in foaling is opposed to this idea.

In most instances, affected colts are born alive, are apparently well developed, and when observed in the recumbent position, appear perfectly normal. In some cases, however, such animals show a lack of vitality, even when lying down, resting the nose on the ground, with eyes half closed, the ears drooping, and the hind legs extended, instead of forward under the body (Fig. 1). As a rule, the colt makes several attempts to rise, but is unable to do so because of weakness, hence the term "weak colts." If an affected foal is assisted to the standing position and the legs are placed in position, it may remain standing for a few moments and even take a step or two. In most instances, it is impossible for such a colt to stand without support, because of the decided contraction of

the flexor tendons in the fore legs, which causes a knuckling-over and an extension of the flexors of the hind legs. The latter condition in many cases causes the animal to stand on the posterior part of the fetlock. Some of these colts, when supported, make an effort to nurse, while others make no attempt to do so.

In some instances, the breathing is labored. The pulse rate is 100 to 130 per minute. A marked jugular pulse is sometimes noted. The animal usually lives from one to three or four days, gradually getting weaker, and finally dies without a struggle.

Occasionally a colt of this kind, after careful nursing, will gradually acquire strength and live. Such animals as it has been possible to observe, however, have never made a complete recovery. The legs remain deformed; in fact, seem to grow worse with age, eventually developing enlargement of the fetlocks and carpal joints (Fig. 2). The majority of cases do not show visibly enlarged thyroids, but in some a slight swelling is apparent. Here, as in adult horses, it is sometimes difficult, even by autopsy, to distinguish a slightly enlarged thyroid from one that is normal. It has not been possible to make comparisons of the size of large numbers of thyroid glands of affected colts with those of normal colts. It is quite likely that such comparative study, however, would show that the former are larger on the average than the latter, a fact which is true in the case of affected pigs.

Autopsy—Our autopsies of horses consisted of the examination of one aged mare and four newborn weak colts. The mare was affected with a very prominent goitre, but otherwise appeared to be in good health. No definite history of the duration of the goitre could be obtained. She had given birth to seven colts, all of which were apparently normal, except the last one, which was weak, and died shortly after birth. She had only been in a goitrous district for two years, and the weak colt was born after this time. This mare was killed and autopsy showed that all organs except the thyroid glands were normal. The thyroids were much enlarged, each being about the size of a baseball and somewhat lobulated.

Careful autopsy of the four weak colts did not reveal the presence of marked enlargement of the thyroids. In fact, in three of these colts, there was such a slight enlargement that it could hardly be designated as such. In one case, the thyroids were about the size of large hen eggs and the swelling was easily visible in the living animal. In two cases, there was a marked dilation of the heart, the left ventricular wall being no thicker than the right and measuring from ten to thirteen millimeters. In the others, the heart was apparently normal. In one case, there were a few hemorrhages on the spleen; in another, a congestion of the kidneys and liver. All cases showed contraction of the flexors in the forelegs and extension of these same structures in the hind legs. The bones in all were apparently normal. All other organs were apparently normal.

CATTLE

Many adult cattle of both sexes in the goitrous districts are affected with enlarged thyroids, but this condition does not seem to be nearly as prevalent among this species as is the case with horses. In fact, the majority do not show this condition upon casual examination. The fullness of a cow's neck in the region of the thyroids would naturally tend to hide a slightly enlarged gland. It is quite possible that a careful examination of many animals would reveal the presence of a large number of enlarged thyroids, but it is obvious that it would be difficult even for an experienced observer to detect a slight enlargement by clinical examination. Many cows which give birth to so-called "big-neck" calves, have apparently normal-sized thyroids. Whether or not microscopic changes are present in the thyroids of all cows which give birth to goitrous calves, has not been determined. Aside from the presence of goitre, in those adult animals in which it occurs, there seems to be no disturbance of the general health.

It is variously estimated by stockmen that from 70 to 80 per cent of all calves born in a goitrous district are affected with goitre at birth. The majority of these calves are alive

at birth, but a few, as evidenced by reports and our observation, are stillborn. Reports as to the number of fatalities occurring among newborn goitrous calves are somewhat conflicting. In those goitrous sections where the winter breaks early and spring is warm, it is generally stated that this trouble does not cause any serious losses; that the calves are apparently normal, except for the enlarged thyroids. The swelling, it is reported, rapidly diminishes in size and usually disappears within a few months. On the other hand, in those localities where the winter is long and spring finds an abundance of snow and cold weather, it is stated that many calves die because of "big-neck." In those regions it is also said that not only are the calves affected with goitre, but that they are weak. Many stockmen even assert that some of the calves show weakness, but not goitre. That goitre causes weakness is no doubt true and that losses are greater from this trouble when calves are born in cold weather, is equally evident. However, this can be explained by the fact that contagious abortion also occurs in some of the goitrous sections and was not recognized prior to our investigation. It is evident that many of the so-called "weak calves" were premature and that the two conditions were confused. In some instances, as proven by our observation, both conditions existed, but complement fixation and agglutination tests of a number of cows showed that the two conditions are entirely distinct and not necessarily associated. It is the opinion of many stockmen in those districts where the calf mortality is high, that calves born in the fall are more likely to live. For this reason, many cows in these districts are bred for the production of fall calves. If this opinion is correct, it is probable that this is due to the fact that weather conditions are the more favorable in the fall and calves have a better chance of recovering, even if weak because of goitre.

The enlargement of the thyroids in newborn calves varies with a slight, almost imperceptible swelling, to one of great size. The thyroids of the calf shown in Fig. 3 weighed 360 grams. Occasionally, the thyroids weigh 500 grams. If the enlargement is only moderate, the calf seems to be otherwise

in good health, and although it is slower to get on its feet than a normal calf, when this is accomplished, it apparently experiences no further inconvenience. Many affected calves showing marked weakness, are at first unable to rise, and therefore must be assisted, but with proper care and nursing, will in time become stronger, take nourishment, and rapidly recover. It is said that in some instances a large swelling will cause difficult breathing and suffocation. Such cases have not come under our observation, but it is quite possible that a marked enlargement of the thyroids could mechanically interfere with breathing, either by pressure on the trachea or larynx, or interfere with the nerve supply. Extensive hemorrhage and oedema, which is a frequent local accompaniment of goitre, might also extend to the respiratory passage and thus affect breathing. In rare cases, there is also manifested a partial hairlessness, as is well illustrated in Fig. 3. All affected calves show a marked jugular pulse. Those animals that live, show a comparatively rapid diminution in size of the thyroids in the first few weeks of life, followed by a more gradual reduction which continues and results in complete disappearance of the swelling in most cases within a few months to one year. In some cases, a slight swelling may persist longer and even remain throughout adult life.

Autopsy—In those cases where there was marked thyroid enlargement, autopsy immediately after birth showed a well-rounded swelling in the region of the larynx. The skin over this swelling was quite tense. The subcutaneous tissue over the thyroids showed extensive infiltration with blood and lymph which extended around on both sides of the glands. After removal of the hemorrhagic extravasate, the thyroids were seen to be very dark in color, appearing much like the clotted blood which surrounded them. In shape, they resembled the normal glands, being uniformly enlarged and extending almost entirely around the trachea. In consistency, the glands were very friable and easily crushed. The abundant hemorrhage and marked congestion no doubt account for the rapid diminution in size of the swelling in the first few weeks of life. The heart showed dilation; the wall of the left ventricle being

little heavier than that of the right. In some cases, hemorrhages occurred in the body lymph nodes, pericardium, and capsules of kidneys and liver. The kidneys and the spleen sometimes showed congestion, while in other cases all tissues and organs except the thyroids and heart were normal.

Autopsies of calves several weeks old revealed a somewhat different condition. In such a case, the skin over the swelling in the neck was loose, there was a total absence of hemorrhage and oedema in the subcutaneous tissue and surrounding the glands. The thyroids appeared normal in shape and color. If congestion was present, it was only slight. The glands show a uniform enlargement and may be several times their normal size. In consistency, they were softer and more friable than normal. The sectioned surface was granular in appearance. All other organs were apparently normal.

HOGS

Our observation of the thyroids of sows which have farrowed hairless pigs has been confined to two cases. In both instances, the sows were killed at the time of parturition because of dystocia and the uterus of each contained seven hairless pigs. It is practically impossible to detect thyroid enlargement in a living hog and as such a condition does not seem to interfere with the health of adult hogs, such of these animals as are seen in goitrous districts appear to be perfectly normal.

Thyroid disturbance in hogs manifests itself chiefly in the form of newborn hairless pigs. Just what percentage of pigs in goitrous districts are born hairless we are unable to say, but it is obvious that the condition is serious, as many stockmen have practically quit trying to raise hogs. Hairless pigs are sometimes dead at birth, but the majority are born alive and die a few hours thereafter. Occasionally, a hairless pig will live and in a few weeks be apparently normal. Hairlessness does not always occur to the same degree in litters, nor does it affect all litters from an individual sow under apparently similar conditions. In some cases, the entire litter may be affected; in others, only a portion of the litter will show hair-

lessness, while the rest will be apparently normal. Again, some or all of the individuals in the litter may show only a slight loss of hair or they may be covered with a thin coat of fine, downy hair. When sows are kept under apparently identical conditions and given the same feed and water, some will farrow normal pigs, while the pigs of others will be hairless. Sows which farrow hairless pigs one year may have normal pigs the following year under similar conditions.

Although affected pigs are usually spoken of as being hairless, this is not entirely true. The tactile hairs on the face and the eyelashes are usually well developed, and there are usually a few hairs on the poll, along the median line of the back and on the tip of the tail. Live hairless pigs always show weakness and loss of vitality in proportion to the degree of hairlessness. If entirely bald, they usually remain lying on their sides, being unable to rise. If disturbed, they utter a peculiar suppressed squeal. If affected pigs are only partially hairless, they may have strength enough to walk and even to nurse. The amnion usually dries and adheres firmly to the skin of a newborn hairless pig. Subsequently this amnion cracks and peels off in patches, thus giving the pig a peculiar appearance. If a hairless pig lives a few hours, its skin becomes easily scratched and shows red patches. If exposed to the sun, it soon shows the effects of burning. As a rule, the skin over the shoulders, sides and flanks and the region of the neck, is somewhat wrinkled, thick and pulpy.

Autopsy—As previously stated, our observations of the thyroids of adult hogs have been confined to two sows. Autopsy of these animals showed the thyroids to be congested. The thyroid of one was apparently normal in size, while that of the other was considerably enlarged. This statement does not agree with the one made by *Hart and Steenbock—"The gland . . . in a sow producing hairless pigs is the size of a man's fist." The glands of both individuals, however, showed marked changes in microscopic structure. All other organs were apparently normal.

*Bul. 297. Wisconsin Agr. Exp. Station.

Autopsy of a large number of hairless pigs showed that there was as a rule thyroid enlargement. Our records show that the average weight of the thyroid of hairless pigs is .6466 grams, while that of normal newborn pigs is .18 grams. On the other hand, we have also found that a normal thyroid may weigh as much as .38 grams and the gland of a hairless pig may be so small as to weigh .2 grams. For this reason, thyroid change is not always easily recognized microscopically in hairless pigs. In our work, even microscopic examination has failed to reveal the usual changes in a few instances. In no instance have we found the thyroid so large as to produce a visible swelling externally. The skin of hairless pigs is smooth and velvety, showing, as a rule, here and there reddened irregular areas, due to congestion and hemorrhage, the result of bruising. In some cases, the skin is thickened and pulpy in the region of the neck and shoulders. Incision shows the dermis and subcutaneous tissue to be apparently oedematous, but the fluid usually observed in simple oedema is not evident. The heart in most cases seems to be dilated and the left ventricular wall is no thicker than the right. In the majority of cases, all other organs are normal; however, there were noted in a few instances, petechial hemorrhages in the kidneys, oedema of the inguinal lymph nodes, and subserous hemorrhages of the intestines and heart. These same lesions were also noted in normal pigs which had been layed on and killed by sows in the farrowing pen, so that there is probably no relation between such lesions and goitre.

SHEEP

Each year, from June to Septemebr, thousands of sheep are ranged on the mountains of Okanogan and Chelan counties. These sheep graze at high altitudes above the goitrous valleys. Because of insufficient feed it is necessary to remove the sheep from these ranges in the fall to the southern part of the state to non-goitrous districts where they are bred and wintered. Sheep handled in this manner are said to be free from goitre and give birth to normal lambs. On the other hand, when such sheep are wintered in the goitrous districts the loss of

lambs becomes a serious problem. In one instance, a stockman in the Methow Valley purchased a band of 700 ewes in the fall of 1913. These were bred in October and at lambing time only 17 per cent of the lambs were saved. The majority died from goitre, hairlessness and weakness. Many adult sheep after being in a goitrous district for a few months develop enlargement of the thyroids but otherwise seem to be in perfect health.

Newborn lambs are affected in much the same way as are calves, but the mortality in these animals is as a rule greater. Baldness is also much more commonly associated with goitre in lambs than it is in calves. Many stockmen believe that some affected lambs are weak and do not have goitre, but such cases have not come to our attention. The thyroids of affected lambs do not as a rule show marked increase in size, but occasionally the enlargement is prominent enough to be visible externally. The fullness of the neck and the abundance of wool tend to hide the swelling.

GOATS

Because of the fact that goats are not raised extensively in this state, goitre among these animals is not of great economic importance. However, these animals proved to be our very best experimental subjects because of their extreme susceptibility to goitre. During our investigation we had an opportunity to observe two small bands of goats in goitrous districts. Practically all adult goats in goitrous districts show marked enlargement of the thyroids which sometimes attain the size of baseballs. (Fig. 6). Otherwise such animals seem to be in good health. According to stockmen who have had experience in the keeping of Angora goats, it is almost impossible to raise kids in goitrous sections. This has been confirmed in our work where we had a hundred per cent loss in our experimental animals in 1917. Affected kids may be either alive at birth or stillborn. Those that are born alive usually live for only a few hours. The thyroids in these animals usually show marked enlargement which is easily visible but the size may vary from 9 grams to 78.5 grams in weight.

Most kids are hairless, some are practically covered with very fine hair, while others are apparently normal as far as the coat is concerned. There seems to be no definite and uniform relationship between the size of the thyroids and the degree of hairlessness. Both hairless and well haired kids may show thyroids of varying sizes. Kids born alive are as a rule so weak that they are unable to do more than raise the head and when disturbed sometimes emit a slight sound. The muscles seem to be completely relaxed. Occasionally a newborn affected kid, if well haired, with careful nursing will make a recovery, but by far the majority die.

Autopsy of neworn kids did not reveal the presence of recognizable lesions in other organs except the thyroids and skin. If the thyroids only showed a moderate increase in size, they were uniformly enlarged and retained their normal shape and consistency. Excessive enlargement was accompanied by congestion and hemorrhage, similar to what occurs in calves.

OTHER ANIMALS

Other domestic animals which suffer from this type of goitre are dogs, cats and chickens. Many adult dogs in goitrous districts are affected with enlarged thyroids and it is reported that many puppies are born with goitre. We have had an opportunity to observe many of the former, but the latter have not come to the writer's attention. As far as can be learned, the affection does not seem to cause serious results either in adult dogs or newborn puppies.

It is reported that kittens are frequently born with enlarged thyroids and are sometimes hairless. No study has been made of the condition in these animals.

It has been repeatedly observed by individuals who dress poultry that adult chickens in goitrous districts are commonly affected with goitre. Several cases have been studied and the thyroids were found to show microscopic changes similar in all respects to those occurring in mammals. (Fig 29). However, newly hatched chicks are apparently not affected or at least no trouble is experienced from this source by poultry raisers.

Many tame rabbits and guinea pigs in goitrous districts have been examined but no evidence of goitre has been discovered.

Many of the regions, where goitre in domestic animals is common, harbor an abundance of wild animals and game. Woodchucks, ground squirrels and chipmunks are common. Deer, wild goat, bear, lynx and coyotes are also quite plentiful. As far as can be learned, these animals apparently do not suffer with goitre. That there is some reason for this there is no doubt, but this matter will be discussed more in detail under cause.

MICROSCOPIC STUDY OF THYROIDS

Technique—All tissues used for microscopic study were secured immediately after death and were fixed in either Zenker's fluid, Bouin's picro-formol or a solution of 10% formalin. After fixation tissues were imbedded in paraffin in the usual way and cut 4 microns in thickness. For sections fixed with Zenker's fluid, the eosin and methylene-blue stain was used. Sections fixed with the other fixatives were stained with haematoxylin and eosin and iron haematoxylin.

Structure of Normal Thyroid Glands—The normal thyroid is a ductless gland and consists of a mass of tubules or follicles, supported by a connective tissue stroma and surrounded by a connective tissue capsule.

The follicles of the thyroid are ovoid saccules or branched tubules. They vary considerably in diameter and in the caliber of their lumen. In horses and cattle the follicles are usually quite large, most of them varying in diameter from 70 to 300 microns. In sheep, hogs and goats the follicles are generally smaller, the majority measuring from 15 to 20 microns in diameter. In all animals some follicles may be so small as to present scarcely any lumen, while others appear, from their extreme size (500 to 600 microns) to simulate small cysts. All follicles which possess any considerable lumen contain a peculiar acidophile substance, known as colloid, which is apparently formed by the secretory activity of the granular epithelium lining the follicles.

Colloid is a homogeneous or very finely granular substance which stains readily with eosin. This colloid fills the follicles to a variable degree and as usually seen in sections is partly or entirely detached from the lining cells, by shrinkage due to fixation.

The follicular epithelium consists of a single layer of cuboidal or columnar cells. (Figs. 10, 11, 12, 13, 14 and 15.)

Structure of Thyroids of Animals Affected with Hyperplastic Goitre—In general two important microscopic changes occur in the thyroids of all species of animals affected with this type of goitre; an increase in the number of cells and a decrease or total disappearance of colloid. The microscopic appearance of thyroids of different affected individuals, however, shows such a great variation that it would seem wise to describe in detail the various types of specimens.

Microscopic examination showed the thyroid of an aged goitrous mare to be made up of two types of abnormal follicles, each occurring in groups or areas. The larger part of the whole structure was occupied by what appeared to be tubules from 20 to 35 microns in diameter and lined by simple cuboidal epithelium. In some of these tubules, a well-defined lumen could be distinguished, while others were entirely closed. A few of the tubules showed the presence of a small amount of colloid, but in most of them there was a total absence of this substance. Between the tubules there were numerous apparently normal thyroid follicles from 100 to 300 microns in diameter, containing colloid; 6 to 10 such colloid-containing follicles could be seen in each *low power microscopic field. In another part of the same specimen, there were many long tortuous tubules, apparently the result of an infolding of the basement membrane, and strona of normal follicles and a multiplication of the lining epithelium. These tubules sometimes attained the length of 1 millimeter and were lined by simple columnar cells, which occasionally occurred in two layers. Colloid was almost entirely absent, occurring only in a few of the tubules. A few cysts containing a serous fluid.

*A circular area approximately $1\frac{1}{2}$ mm. in diameter.

some of them several millimeters in diameter, were also present. There was also a slight congestion throughout the specimen.

Notwithstanding the fact that the thyroids in most "weak colts" are only slightly if at all enlarged, microscopic examination showed a marked deviation from the normal in structure. In all cases, the thyroids appeared to be made up of small tubules not unlike those seen in the thyroids of the aged mare previously described. These tubules were 25 to 50 microns in diameter, and were lined by simple cuboidal and tall columnar epithelial cells. Some showed a distinct lumen, while others were completely closed. There was almost a total absence of colloid. On an entire microscopic section occupying an area 15 millimeters square, not over a dozen tubules showed the presence of colloid. A slight congestion was evident in all specimens. (Figs. 16 and 17).

Examination of sections of thyroids from newborn "big-neck" calves showed a marked congestion uniformly distributed throughout the structure, together with extensive hemorrhage. Low power examination showed extreme vascularity, fully half of the specimen appearing to be made up of capillaries and arterioles filled with blood. Follicles were nowhere to be seen, these having completely disintegrated and the secreting cells which lined them lay free, mixed in between the red corpuscles outside of the blood vessels (Fig. 19). Some of these secreting cells lay singly but for the most part they were in groups of 5 or 6 surrounded by the extravasated blood. In some areas, groups of cells lay in a comparatively free space surrounded by blood. In shape, the cells are for the most part columnar, but many appear circular and irregular, being pear-shaped and spindle-shaped. The entire specimen showed a complete absence of colloid. On the whole, an examination of a section gives the impression of an extremely vascular tissue in which there is an abundance of hemorrhage and scattered throughout, a large number of free epithelial cells.

Marked changes occur in such a structure within a few weeks after birth. The hemorrhagic extravasate is rapidly re-

moved and absorbed, congestion is reduced and the size of the gland is materially diminished.

An examination of the thyroids of a six-weeks-old goitrous calf showed the presence of many irregular shaped follicles, varying in size up to 1000 microns or more in diameter. There was apparently an infolding of the lining epithelium, together with the basement membrane and stroma, thus forming papillae (Fig. 20). The lumen of the follicle in most cases was merely a slit-like opening in which there was no colloid. The cells lining the follicles were the tall columnar variety, occurring usually in a single layer, sometimes two, and rarely three layers. (Fig. 21). Mitotic figures were occasionally seen, but were by no means numerous. A few apparently normal colloid containing follicles were also present; an average of one such follicle to each low-power microscopic field could be seen; these varied in size from 50 to 250 microns in diameter. Some of these follicles were well-filled with colloid and circular in shape, but the majority were compressed and irregular, being somewhat longer than wide. The cells lining the colloid-containing follicles were simple columnar. Slight congestion occurred throughout the gland.

Microscopic examination of the thyroids of the two sows which farrowed hairless pigs showed identical structural changes, notwithstanding the fact that in one case the glands were normal in size and in the other much enlarged. The follicles were larger than normal, measuring 50 to 600 microns in diameter. There was a slight ingrowth of the stroma and basement membrane, thus forming an irregular outline for the follicle which in most cases was filled with a serous fluid instead of colloid. The cells lining the follicles were columnar in shape and several layers deep, showing in many places active mitosis. (Fig. 28).

The thyroids of hairless pigs showed considerable variation in microscopic structure. In some cases, they were apparently normal, being made up of well-rounded follicles filled with colloid, and lined by simple cuboidal and columnar cells. Two such specimens have come to our attention and in both cases the pigs were totally hairless. By far the majority of cases showed

marked deviation from the normal structure. The gland may be made up of simple tubules set close together like those seen in the thyroids of "weak colts." The tubules may be widely separated and irregular in shape. The space between the tubules in such a structure is filled with serum, leukocytes, fibroblasts, extravasated blood and exfoliated follicle cells. (Fig 22). Some of the tubules showed a distinct lumen, while others were closed. These latter frequently resemble groups of nuclei imbedded in a mass of protoplasm, and appeared much like giant cells as seen in myeloid sarcomas. There was always more or less congestion and a total absence of colloid. The cells were simple cuboidal and columnar.

Microscopic examination of sections of skin from newborn hairless pigs shows that the hair follicles are apparently normal and contain hair roots which have grown to only about the level of the epidermis.

The microscopic changes in the thyroids of lambs resembled those occurring in the glands of other animals. Although the picture varied slightly in detail, in general the follicles were enlarged, the cells increased in number and there was an absence of colloid.

Microscopic examination of the thyroids of goats revealed changes of a hyperplastic nature similar to that seen in other animals but as a rule a larger number of follicles contained colloid.

CAUSE

It is a known fact that the thyroid has an important relation to metabolism.

Administration of preparation of the gland substances causes in animals greatly increased elimination of nitrogen in the form of urea. Loss of weight and strength indicate that this nitrogen comes from increased tissue-destruction. An increased destruction of the body fat also occurs.*

Loss of thyroid tissue, either through operation or disease greatly reduces both nitrogenous metabolism and oxidation

*Rheinboldt, Zeit. Klin. Med. 1906.

processes. Administration of thyroid extract will reestablish normal conditions under such circumstances.

Decreased thyroid secretion in the young in utero prevents their normal development. This is manifested by cretinism, weakness both physical and mental and trophic disturbances of the skin and its appendages.

The thyroid also seems to be able to destroy or neutralize certain poisonous substances formed as a result of intestinal putrefaction or in metabolism.

Apparent symptoms of intoxication follow complete removal of the thyroids in many species of animals.

Removal of the thyroids is followed by severe anaemia (as low as 2,000,000 red cells), with some leucocytosis, and there occur structural changes in the blood-vessel walls (Kishi)[†]. Benson[‡] reports cytoplasmic degeneration of the liver, kidneys and myocardium. Such effects suggest the possibility of poisonous substances in the blood of animals lacking sufficient thyroid tissue.

Effects of thyroidectomy are more pronounced in carnivora than in herbivora and thyroidectomized carnivora do much better if kept without meat. Blum^{*} reports that thyroidectomized dogs which were doing well on a milk diet, developed marked symptoms when changed to a meat diet. This fact has been interpreted as indicating that toxic materials are formed from meat in the intestinal tract which under normal conditions are neutralized by the thyroid.

In herbivorous animals it may be that a diet like alfalfa hay, especially when high in protein content, has a similar effect to that of meat. In those regions where goitre is common among domestic animals in Washington, alfalfa is fed in many instances almost exclusively. The same practice is of course followed in many non-goitrous districts.

It has been frequently suggested that the cause of enzootic goitre is a deficiency of iodine in the food, or in the drinking water, or in the air of the goitrous district. This is supported

[†]Virchow's Arch. 1904.

[‡]Virchow's Arch. 1902.

^{*}Virchow's Arch. 1900.

by the relative infrequency of enzootic goitre in districts on the sea-coasts, where the iodine-containing sea-water is sprayed through the air and where animals may even drink sea-water. Infection has also been suggested as a possible cause.

The presence of iodine in the thyroid glands was first discovered by Baumann in 1896. Since that time many investigators have studied the iodine content of both human and animal thyroids and have demonstrated that this substance is decreased in amount in the glands of goitrous individuals.

In the past few years, the administration of iodine for the prevention of goitre has been quite commonly practiced. In 1910 Marine[†] reported a series of experiments in which small amounts of iodine were added to water containing brook trout affected with goitre. Beneficial effects followed such treatment.

Welch,* of the Montana Agricultural Experiment Station, in reporting the results of iodine feeding experiments with pregnant sows in goitrous districts, states: "The results from iodine feeding have apparently been very favorable, but as there were no check experiments there is an element of error possible."

Hart and Steenbock[†], of the Wisconsin Experiment Station, report that: "We have successfully corrected the hairless pig trouble by giving the sow during her entire gestation period ten grams of potassium iodide per 100 pounds of feed." Check experiments, however, were not reported in this publication.

Many stockmen in goitrous districts have administered iodine to pregnant animals and report good results following its use.

In the experiments conducted by this Station the work was done with hogs, sheep and angora goats, but many experiments were also carried on in co-operation with stockmen on horses and cattle. The angora goats proved, on account of their extreme susceptibility to this trouble, to be the best experimental subjects and it was possible to completely control the results of the work with these animals.

[†]Bul. No. 7. Dept. of Fisheries, Commonwealth of Penn.

*Bulletin 119. Agr. Exp. Sta., Uni. of Montana.

[†]Bulletin 297. Agr. Exp. Sta., Uni. of Wisconsin.

It has been definitely proved that the administration of iodine in various forms and by different methods will prevent goitre and its associated conditions. On the other hand, no one has succeeded in producing this condition at will by feeding experiments in a sufficient number of cases to assume that this can be done.

It may be that other factors besides the deficiency of iodine in the food and water are responsible for goitre. The fact, however, that iodine when absorbed either from the intestines, the subcutaneous tissue or through the unbroken skin is capable of preventing this malady indicates that this element only is needed to correct the trouble.

As previously stated, wild animals which range in the mountains above the goitrous districts are not affected. This is also true, in a measure, of sheep, cattle, horses, and other domestic animals. Upon investigation it was found that in various localities in these regions there were so-called "deer-licks" that are frequented by deer and other animals which devour a large quantity of the soil. Samples of the soil from one of these "deer licks" have been analyzed by our Chemistry Division and the report shows a high percentage of iodine as compared with similar samples taken from other places in the goitrous districts.

Table I—ANALYSIS OF "DEER LICK" SOIL

Iodine	0.032 %
Water soluble constituents calculated on basis of the following components:	
Sodium bicarbonate	0.1739%
Sodium chloride	0.1118%
Calcium oxide	0.0094%
Phosphorous pentoxide	0.003 %
Total Solids	0.331 %

Iron, alumina, magnesia, silica, potash, organic matter and sulfates were not determined, since they were present in only very small quantities.

Analysis of iodine content of soils from a goitrous district show the following results:

Virgin soil	Iodine	.00153571%
Cultivated soil	Iodine	.00161397%

The Iodine Content of Foodstuffs—In 1915 and 1916 Forbes and Beegle* made a determination of the iodine content of foodstuffs collected from goitrous and non-goitrous areas. To quote from their report, "This. . . . series of estimations was intended especially as an investigation of the geographic distribution of iodine in foods, with the idea that the relation of the results to the geographic distribution of goitre might be enlightening."

In summarizing the authors among other things have this to say in reference to the table of results: "This table impresses one with the smallness of the proportion of our food products which contain iodine, the minute quantities in which iodine is ordinarily found, and the haphazard nature of its distribution."

With reference to iodine content of foods from goitrous areas the authors state: "The iodine content of foods grown in these goitrous regions appears not to be lower than in foods grown elsewhere—nor is a high iodine content characteristic of foods grown in goitrous regions."

The following table is taken verbatim from Bul. 299, Ohio Agricultural Experiment Station. It shows the iodine content of samples which were sent from Washington and represent both goitrous and non-goitrous regions:

*Bulletin 299. Ohio Agr. Exp. Station. The Iodine Content of Foods.

Table II.—IODINE CONTENT OF FOODS
(Dry basis unless otherwise stated)

Sample No.	Sample	Locality	Iodine		Remarks
			Content		
733—	Barley.....	Exp. Sta., Pullman, Wash.	None.....		Non-goitrous region
734—	Beet, sugar.....	Exp. Sta., Pullman, Wash.	None.....		Non-goitrous region
735—	Carrot.....	Exp. Sta., Pullman, Wash.	None.....		Non-goitrous region
736—	Clover, red.....	Exp. Sta., Pullman, Wash.	None.....		Non-goitrous region
737—	Kale.....	Exp. Sta., Pullman, Wash.	None.....		Non-goitrous region
738—	Oats.....	Exp. Sta., Pullman, Wash.	None.....		Non-goitrous region
739—	Oats, plant.....	Exp. Sta., Pullman, Wash.	None.....		Non-goitrous region
740—	Peas.....	Exp. Sta., Pullman, Wash.	None.....		Non-goitrous region
741—	Pearl, rutabaga.....	Exp. Sta., Pullman, Wash.	None.....		Non-goitrous region
742—	Wheat.....	Exp. Sta., Pullman, Wash.	None.....		Non-goitrous region
743—	Alfalfa.....	Floyd Zimmerman, Twisp, Wash.	None.....		Irrigated goitrous region
744—	Oat hay.....	Floyd Zimmerman, Twisp, Wash.	None.....		Not irrigated goitrous region
745—	Alfalfa.....	W. C. Hanks, Winthrop, Wash.	None.....		Second crop; irrigated goitrous region
746—	Alfalfa.....	Alan Wetzel, Winthrop, Wash.	None.....		Irrigated, goitrous region
747—	Alfalfa.....	Frank Bean, Winthrop, Wash.	None.....		Irrigated goitrous region
748—	Alfalfa.....	C. W. Gunn, Winthrop, Wash.	None.....		Irrigated goitrous region
749—	Apple.....	W. C. Hanks, Winthrop, Wash.	None.....		Irrigated goitrous region
750—	Apple, Jonathan.....	W. C. Hanks, Winthrop, Wash.	Trace.....		Not irrigated goitrous region
751—	Apple, Rome Beauty.....	W. C. Hanks, Winthrop, Wash.	Trace.....		Not irrigated goitrous region
752—	Apple, Wagener.....	W. C. Hanks, Winthrop, Wash.	None.....		Not irrigated goitrous region
753—	Beet, Sugar.....	W. C. Hanks, Winthrop, Wash.	Trace.....		Goitrous region
754—	Carrot.....	W. C. Hanks, Winthrop, Wash.	None.....		Goitrous region
755—	Corn.....	W. C. Hanks, Winthrop, Wash.	None.....		Goitrous region
756—	Corn.....	W. C. Hanks, Winthrop, Wash.	None.....		Irrigated, virgin soil, goitrous region
757—	Oats.....	W. C. Hanks, Winthrop, Wash.	Trace.....		Irrigated, old alfalfa field, goitrous region
758—	Oats.....	W. C. Hanks, Winthrop, Wash.	None.....		Irrigated goitrous region
759—	Oat straw.....	W. C. Hanks, Winthrop, Wash.	None.....		Irrigated goitrous region
760—	Oat straw and grain.....	Frank Bean, Winthrop, Wash.	None.....		Irrigated goitrous region
761—	Potato.....	W. C. Hanks, Winthrop, Wash.	Trace.....		Irrigated goitrous region
762—	Timothy.....	C. W. Gunn, Winthrop, Wash.	None.....		Goitrous region
763—	Water, Bear Creek.....	W. C. Hanks, Winthrop, Wash.	0.0000077.....		Goitrous region
764—	Water, well.....	W. C. Hanks, Winthrop, Wash.	0.0000120.....		Goitrous region
765—	Wheat, Blue Stem.....	C. W. Gunn, Winthrop, Wash.	None.....		Not irrigated goitrous region
766—	Wheat Hay.....	C. W. Gunn, Winthrop, Wash.	None.....		Heads half-filled; half of stalk included; goitrous region
767—	Wheat plant.....	Alan Wetzel, Winthrop, Wash.	None.....		Goitrous region

Iodine Content of Thyroid Glands—During our preliminary investigation we collected 112 thyroid glands from both normal and goitrous animals of various species. Iodine determinations of these glands according to Kendall's method were made for the purpose of comparison and study.

Table III shows in detail the weights of the thyroids collected their source and the per cent of iodine content.

These analyses were made by the Chemistry Division, State College of Washington.

Table III—WEIGHTS AND IODINE CONTENT OF THYROIDS

	No. of Analyses.	Weight of Glands in grams		Average Weight...	Per Cent of Iodine Content		Average Percent-age Iodine Content.....
		Minimum.	Maximum.		Minimum.	Maximum.	
Newborn normal pig..	13	0.02	0.4	0.18	0.02580	0.27770	0.10020
Normal hog (450 lbs.)	1	5.20	18.1	10.08	0.00213	0.02106	0.00852
Normal hog (250 lbs.)	1	..	..	..	.....	.....	.....
Normal hog (250 lbs.)	1	..	..	..	.....	.....	.....
Newborn hairless pig.	45	0.20	1.9	0.65	0.00343	0.04300	0.01443
Normal adult sheep..	11	3.15	7.95	4.88	0.00005	0.01721	0.00244
Adult goitrous ewe...	1	72.00	..	..	0.00460	.....	.....
Newborn goitrous lamb	6	7.60	32.8	19.00	0.00324	0.00715	0.00534
Adult Angora doe with goitre	3	17.30	62.3	44.40	0.00410	0.02140	0.01190
Newborn Angora kid with goitre	28	9.20	78.5	31.78	0.00137	0.01220	0.00500
Newborn weak colt...	1	12.00	..	..	0.00710	.....	.....

A careful study of this table shows that variation in size and iodine content of thyroids in both normal and hairless pigs is not striking. In other words an examination of only a few glands would not reveal any great difference. In many cases the thyroids of normal pigs may be as large or larger than those of hairless pigs and the iodine content may be less. In

order to see the difference it is necessary to examine the glands of a comparatively large number of pigs.

Thus it will be seen that although individual cases do not show a great difference, an examination of a large number of glands shows that the average weight of those from hairless pigs is much greater than of those from normal pigs and the average iodine content is much less.

In the case of sheep it is hardly possible to make comparisons of the above examinations because the normal thyroids were those of adults and the goitrous glands were from newborn lambs. There is, however, a striking difference in the size of the glands of these animals. In spite of the fact that the goitrous glands were from newborn lambs the weight of the smallest was almost as great as the weight of the largest glands from an adult normal sheep. The percentage of iodine content in this case was smaller in normal glands than in goitrous glands but this may have been due to age and possibly to seasonal influences. The normal glands were obtained in the winter while the goitrous ones were collected in the spring. Unfortunately we did not have normal glands of newborn lambs for study. It is hoped that such glands may be collected in the future.

A comparative study of goitrous and normal glands of goats is not possible at this time as we have been unable to collect the latter. The difference in size, however, is so striking clinically and on autopsy that little discussion is necessary. The iodine content as seen in the table is very small and the average percentage is even lower than that found in thyroids of hairless pigs.

EXPERIMENTAL WORK WITH ANIMALS

Plan of Experiments—After conducting our preliminary investigation it was decided to do some experimental work with a view of determining if possible the cause and method of control of goitre and associated conditions in domestic animals. After consulting all of the available literature on the subject we thought it advisable to attack the problem from some other angle than had previously been attempted up to that time. Apparently no one had been able to produce this type of goitre

at will but we thought that possibly this might be done. In our first work a series of feeding experiments were outlined whereby we thought it possible to determine the cause. In order that this work might be conducted most economically it was thought best to do it in a goitrous district. Accordingly a location was selected in the Methow Valley in Okanogan County near Winthrop, Washington, where goitre is very prevalent. A series of thirty pens were built in a row, each measuring 30 feet by 8 feet with a shed 6 feet deep in the north end, facing south for shelter. The walls were boarded up 4 feet in height so as to prevent communication and obviate any possibility of feed getting from one compartment into another.

The animals used in these feeding experiments consisted of non-pregnant does, ewes and sows. These species were chosen because they represented the variations in goitre and being small they could be used more economically than horses and cattle. Two groups of animals were used; one group consisted of normal females from non-goitrous regions and the other consisted of females from goitrous regions which were known to have given birth to goitrous young the previous spring. The normal animals were to serve as checks for the goitrous ones. Each group of animals was divided into five lots. All animals were fed a ration of alfalfa hay and corn; hogs received equal proportions of each, while sheep and goats received a mixture of one part corn and four parts alfalfa hay. The distribution of the animals and the method of feeding and watering with regard to source of feed and water can best be seen by referring to Table IV.

The iodine content of the water used in these experiments was as follows:

	Iodine Content
Methow River water (goitrous region)	.000114%
Methow Valley spring water (goitrous region)	Trace
Artesian water (non-goitrous region)	Trace

Table IV.—PLAN OF EXPERIMENTS BEGUN NOV. 11, 1915

Lot No.....	Pen No.....	No. of goitrous does..	No. of normal does..	No. of goitrous ewes..	No. of normal ewes..	No. of goitrous sows..	No. of normal sows..	Source and Kind of Feed	Source of Water
I	1 to 6 inc.	3	3	3	3	3	3	Alfalfa hay and corn grown in a non-goitrous region.	Methow River, goitrous region
II	7 to 12 inc.	3	3	3	3	3	3	Alfalfa hay and corn grown in a non-goitrous region.	Spring water from the Methow Valley, a goitrous region
III	13 to 18 inc.	3	3	3	3	2	2	Alfalfa hay and corn grown in a goitrous region	Artesian water from Pullman, a non-goitrous region
IV	19 to 24 inc.	3	3	3	3	2	2	Alfalfa hay and corn grown in a goitrous region.	Equal parts of Methow River and spring water boiled for 20 minutes
V	25 to 30 inc.	3	3	3	3	2	2	Alfalfa hay and corn grown in a non-goitrous region.	Equal parts of Methow River and spring water boiled for 20 minutes
Total number animals used		30		30			24		

In planning the experimental feeding for the animals in Lots IV and V we had in mind the possibility of organisms being the cause of goitre and it was hoped, if this theory had any foundation, that we could determine whether such pathogens were present in the water or feed or both. On the other hand it was assumed that if the cause was of chemical origin that there would be a variation in the effect upon the offspring of the animals in these lots because feed from a goitrous region was used in one lot and feed from a non-goitrous region in the other.

The above feeding experiments as outlined were started on November 11, 1915, and continued for a period of almost two years. The animals were confined in the pens as indicated from the time the work was started until May and June, 1917, after they had given birth to young that spring. They were then turned out for the first time.

In order to facilitate the keeping of records all goitrous females were designated by odd numbers and confined to odd numbered pens, and all normal females were designated by even numbers and confined in even numbered pens.

It was originally intended to use three females in each pen in order that one or more young would be assured. This was not carried out in the case of sows, as we were unable to obtain the desired number; hence the reason for using only two sows in each of the pens in Lots III, IV and V.

All experimental animals were bred at the proper time in the fall of 1915. Beginning at this time, accurate records were kept of date of breeding, date of births, character, condition and number of young, etc.

Results of Experiments with Goats—Unfortunately our experiments the first season with goats were vitiated because of impotency of the buck used. A number of the goitrous does gave birth to young in January and February, 1916, as a result of previous breeding of which we were unaware at the time the animals were purchased. Because of this we did not attempt to draw any conclusions from the results of that year's experiments with these animals.

In the fall of 1916 another buck was purchased and all does were again bred. Of the thirty does in this experiment twenty-two gave birth to thirty young in the spring of 1917. Three does died and five failed to conceive; all lots, however, were represented.

All young dropped by the twenty-two does were affected with goitre at birth and many were partially or totally hairless. Some were stillborn, while others were alive and died within a few hours after birth.

The results would indicate that the cause was present in both spring and river water and feed from a goitrous region.

It also indicated that infection played no part in the cause of goitre.

Although goitre and hairlessness in all cases were unmistakable there was a slight variation manifested in the newborn kids in the different lots. Those born in Lot IV showed the largest thyroids, the most pronounced cases of hairlessness and all were dead at birth. None of the goitrous does in this lot gave birth to young, but as the condition was so pronounced in the young of the normal does we did not consider that our results were other than satisfactory.

Goitre and hairlessness was much less pronounced in the young born in Lot V; three of the five kids were alive at birth and one lived five hours. The condition was somewhat more pronounced in Lots I, II, and III, but not by any means as much as in Lot IV. Both goitre and hairlessness was manifested to about the same degree in the young in the first three lots. The reader's attention is called to the fact that the animals in Lot IV were given both feed and water from a goitrous region, while those in the other lots received either water or feed only from a goitrous region.

During the summer of 1917 the does were turned out on pasture in the goitrous region, but were again confined in pens in the fall and bred. At this time we had twenty-four of the original thirty does, six having died. These twenty-four does were divided into four lots and given feed grown in a goitrous district and Methow river water. The ration consisted of one part corn and four parts alfalfa hay. The animals were segregated and treated as shown in Table V.

Table V.—RESULTS OF IODINE TESTS, 1917-1918
(Six does in each lot)

Lot.....	Form of Iodine Used.....	Dose.....	Frequency of Administration..	Method of Administration..	No of Young Born in Lot....	Condition of Young at Birth.....
I	The six does in this lot were used as controls and not treated.				10	All showed marked goitre and many were hairless; 8 were stillborn; the other 2 died shortly after birth.
II	Pot. Iodide	2 grains in $\frac{1}{2}$ oz water	Daily during gestation	Per orem	5	Normal in every respect. No indication of goitre; bodies well covered with hair.
III	Tincture of Iodine	5 mils. of 10% solution	Weekly during gestation	Subcutaneously	7	Normal in every way No indication of goitre; bodies well covered with hair.
IV	Tincture of Iodine	1 mil.	Weekly during gestation	Poured on skin of back	8	Seven were normal. One showed a very slight thyroid enlargement but was well haired and otherwise normal.

The above experiments prove beyond a doubt that iodine administered per orem, subcutaneously or on the skin can be absolutely depended upon to prevent this type of congenital goitre. It is the first time to our knowledge that experiments of this character have been conducted with animals where the results were absolutely controlled with check animals.

During the summer of 1918 the does were turned out on pasture. Several died because of advancing age and the rest were again used for experimental work in the fall. The method of feeding was the same as the previous season and the animals were divided into three lots and treated as shown in Table VI.

Table VI.—RESULTS OF IODINE TESTS, 1918-19

Lot No.....	No of Does Used.	Treatment Previous to Gestation, 1917-18.....	Treatment 1918-19.....	No. of Young Born in Lot...	Condition of Young at Birth.....
I	6	Received iodine	None	3	Two, each dropped by a different doe, were normal in every respect. One was stillborn, hairless and had goitre.
II	5	Untreated Controls	1 mil. of tincture of iodine poured on skin weekly during gestation	2	Normal
III	6	Received iodine	1 mil. of tincture of iodine on skin once every two weeks during gestation	3	Normal

It is obvious from the results in Lot I that although a female may retain a sufficient amount of iodine if treated during a previous pregnancy to prevent goitre in some cases, this cannot be depended upon. In order to be certain of results, iodine must be given during every gestation period.

It is interesting to note the record of doe No. 20 for four successive gestation periods. In 1916 and 1917, when untreated, this doe gave birth to young affected with goitre and hairlessness. In 1918, after being treated by subcutaneous injections of iodine, she gave birth to perfectly normal twins. In 1919, without treatment, she again gave birth to goitrous and hairless young.

It might be stated at this time that besides preventing goitre in newborn kids the administration of iodine had a decided influence on the doe treated. Many of these does showed before treatment an enlargement of the thyroid glands. In some cases the glands were as large as a man's fist and hung like a pendulum. Iodine treatment caused a

material decrease in the size of these glands in all cases. Although the glands were not reduced to normal size, in some of the more pronounced cases the reduction in size was so marked that there seemed to be only a fold of skin where formerly the glands were very prominent.

Results of Experiments with Sheep—The results of experimental work with sheep was very unsatisfactory and inconclusive during the first two years, when feeding experiments were conducted with a view to determining the cause of goitre.

The results of these feeding experiments are shown in Table VII.

Table VII.
Results in 1916

Lot No.....	Pen No.....	No. of Ewes in Experiment Normal.....	No. of Ewes in Experiment Goitrous.....	No. of Ewes Having Young Normal.....	No. of Ewes Having Young Goitrous.....	No. of Lambs in Lot.....	Condition of Lambs at Birth.....
I	3 & 4	3	3	3	2	6	All lambs were normal. There was no indication of goitre.
II	9 & 10	3	3	3	3	6	The lambs from the goitrous ewes showed slight thyroid enlargement but were alive and otherwise normal. Lambs of normal ewes were normal in every way.
III	15 & 16	3	3	3	3	9	All lambs were normal. There was no indication of goitre.
IV	21 & 22	3	3	2	3	7	The lambs of all goitrous ewes were perfectly normal. Twin lambs were dropped by two of the normal ewes. All were affected with goitre and one pair were woolless and stillborn.
V	27 & 28	3	3	3	3	7	All lambs were normal. There was no indication of goitre.

Results in 1917

I	3 & 4	3	3	1	0	2	Normal in every respect.
II	9 & 10	3	3	3	2	6	The lamb of one goitrous ewe showed slight thyroid enlargement, but was otherwise in perfect health. All other lambs were perfectly normal.
III	15 & 16	3	3	2	3	6	The lamb of one goitrous ewe was stillborn, thinly woolled and showed thyroid enlargement. All other lambs were normal.
IV	21 & 22	2	3	2	3	7	One goitrous ewe and two normal ewes gave birth to goitrous lambs. All other lambs were normal.
V	27 & 28	3	3	1	1	3	Twin lambs from normal ewe showed slight thyroid enlargement. Lamb from goitrous ewe was normal.

No explanation is offered for the irregularity of results in these feeding experiments with sheep. It is difficult to see why a goitrous ewe in Lot II should give birth to a goitrous lamb in 1916 and under the same conditions of feed and care should give birth to a normal lamb in 1917. It also seems strange that two normal ewes in Lot IV should give birth to goitrous lambs after the first gestation period, while three goitrous ewes under like conditions drop normal lambs. Needless to say, this lack of uniformity in results is puzzling. It seems certain, however, that individual sheep show a great variation in susceptibility to goitre and on the whole are much less susceptible than goats. In some cases it would appear that an immunity is developed, but this is hardly probable.

During the summer of 1917 all of the experimental ewes were pastured in a goitrous region. At this time there remained twenty-seven of the original thirty, three having died. In the fall these twenty-seven ewes were divided into four lots, as shown in Table VIII, confined in pens and given feed grown in a goitrous region and Methow river water.

Table VIII.—RESULTS IN 1918

Lot.....	No. of Ewes..	Behavior Previous 2 Years...	Ration.....	Medicinal Treatment.	Condition of Young at Birth.....
I	7	Gave birth to goitrous young	1 part corn 5 parts alfalfa hay	2 grains pot. iodide per orem daily during gestation	Normal
II	6	Gave birth to normal young	1 part corn 5 parts alfalfa hay	None	Normal
III	7	Gave birth to normal young	1 part oats 5 parts alfalfa hay	None	Normal
IV	7	Gave birth to normal young	1 part barley 5 parts alfalfa hay	None	Normal

In the first lot the administration of potassium iodide apparently prevented goitre in the young, but the results are en-

tirely emperical, as the other three lots can not be considered as suitable controls.

In the fall of 1918 the ewes were divided into three lots, given a ration of one part corn and five parts alfalfa hay grown in a goitrous region and Methow river water. All animals were treated during pregnancy; the first lot by administration of two grains potassium iodide per orem once daily, the second by subcutaneous injection of five mils of a ten per cent solution of tincture of iodine once a week and the third by pouring one mil of tincture of iodine on the skin of the back. All lambs dropped by these ewes in the spring of 1919 were perfectly normal. Here again the results must be considered as emperical, as suitable checks could not be made.

Experiments with Hogs—The results of experiments with hogs were even more disappointing than those with sheep. After conducting experiments with sows for two years, as outlined in Table IV, we found that it was impossible to cause the production of hairless pigs with any degree of certainty or uniformity. Twelve of the twenty-four sows used were goitrous animals; that is, they were known to have farrowed hairless pigs before they were used for experimentation. In selecting them we were careful to choose individuals that had farrowed entire litters of hairless pigs in the spring of 1915. In the spring of 1916 all sows except three farrowed perfectly normal well-haired pigs. One litter of five farrowed by a goitrous sow (No. 77) in Lot IV was hairless. Two other litters, one farrowed by a goitrous sow in Lot I and another by a normal sow in Lot V, showed a slight loss of hair, but the pigs were strong and most of them were saved.

Although there was no uniformity in the outcome of the experiments after the first gestation period, it is interesting to note that the only sow which farrowed typical hairless pigs (No. 77) was in Lot IV. In this lot both feed and water from a goitrous region were used. It is of course strange that the other sow in the same pen did not show the same results; this may, however, be due to a variation in susceptibility.

In the spring of 1916 all of the sows were rebred for fall pigs. In the fall all but five of the sows farrowed. All pens except one (No. 24 in Lot IV) were represented by one or more litters. All sows which farrowed had normal well-haired pigs except No. 77 in Lot IV; this sow again farrowed hairless pigs, seven in number. Her mate farrowed a normal litter. It was unfortunate that the two normal sows in the same lot did not conceive, but this did not apparently interfere with the results because these sows farrowed the following spring and their pigs were normal.

All sows were again bred in the fall of 1916 and all but one farrowed the following spring. Sow No. 77 in Lot IV, which previously farrowed two litters of hairless pigs, this time farrowed a litter of five, four of which were normal; the fifth was partially hairless, but lived.

As this method of experimentation seemed fruitless from the standpoint of determining the cause of hairlessness in newborn pigs it was abandoned in the spring of 1917. During the summer the sows were pastured on green alfalfa in a goitrous region.

During our preliminary investigation we were informed by stockmen that certain rations seemed to be responsible for hairlessness. They generally considered that if pregnant sows were fed exclusively on alfalfa hay or alfalfa hay and oats, hairless pigs would result, while if alfalfa hay was supplemented with corn or barley the condition would be prevented. In order to determine the truth of this belief, a series of experiments were begun in the fall of 1917. The sows were divided into three lots and maintained during gestation on feed and water from a goitrous region. The rations were as follows:

Lot I received equal parts of alfalfa hay and corn.

Lot II received a ration of one part alfalfa hay and two parts barley.

Lot III received a ration of five parts alfalfa hay and one part oats.

In the spring of 1918 all but two of the twenty-four sows farrowed. In every instance the young were perfectly normal and well haired. The ration used in Lot II seemed entirely

inadequate to maintain the sows in good physical condition, but the litters in this lot were more uniform in size and apparently more thrifty than in the other lots. Sow No. 77, which was in Lot I, farrowed five normal well-haired pigs.

It is quite evident from the above experiments that hogs are much less susceptible to goitre than either goats or ewes. It is a known fact that hairless pigs are more common some seasons than others. This may be due to a variation of iodine content in feed and water in different seasons. During the same seasons that our experiments were being conducted many stockmen living near our temporary station were experiencing trouble with hairless pigs. It would seem then that we should have experienced the trouble during that time also but this was not the case. Few stockmen are in the habit of feeding the amount of grain that our sows received and this may in a measure account for the difference in results. Although it has not been proved by analyses, it may be that grain supplies iodine or some other material which is capable of overcoming hairlessness in pigs.

In the fall of 1918 our sows were again placed on a corn and alfalfa ration. They were divided into four lots; the sows in three lots were treated with iodine in various ways, the same as the experimental goats, and the fourth was left untreated. In all cases the farrowed pigs were normal so the details of this experiment are here omitted.

Field Experiments—Because of the excellent results which followed the use of iodine in the treatment of pregnant Angora does and Merino ewes for the prevention of congenital goitre, it was thought advisable to try out this method on other species of animals. In order to do this most economically we decided to conduct field experiments in co-operation with stockmen in goitrous regions where congenital goitre was especially prevalent. We realized that this method of conducting the work would by no means be ideal from an experimental viewpoint because suitable control experiments could not be maintained. However, the practical results of this work have been very gratifying.

In the fall of 1918 we offered to furnish tincture of iodine free, for the treatment of pregnant animals, to all applicants who in turn would agree to furnish a full report of the results. All animals were to be treated by pouring tincture of iodine on the skin once every two weeks, beginning as early as possible in pregnancy. Cows and mares were to receive doses of one teaspoonful and other animals half this amount. For various reasons this schedule of administration was not followed in all cases. Most of the sheep treated during pregnancy were given a total of only three doses of about a teaspoonful each time; the iodine was applied to the skin inside the flank. In many cases treatment was not started until pregnancy had advanced weeks or months. Up to date complete reports have been received from twenty-five stockmen. The following treated animals having given birth to young: 77 mares, 137 cows, 28 sows and 66 sheep. In every instance the owners reported perfectly normal young. Although, as previously stated, it was not possible to conduct suitable check experiments, the fact that these same stockmen had previously experienced more or less trouble with goitrous animals before they used iodine, would seem to indicate that iodine was responsible for preventing the condition.

Gestation Period of Experimental Animals—Early in our investigation we recognized the fact that contagious abortion was common among cattle in goitrous regions. In many cases contagious abortion and goitre occurred simultaneously in the same animal. Complement fixation and agglutination tests proved definitely that the two conditions were in no way related. In order, however, to get further data regarding this phase of the problem, it was considered advisable to keep accurate records of the gestation periods in all our experimental animals.

The normal gestation period of sheep, goats and pigs reported by Fleming* is as follows:

"The sheep and goats go with young about five months. M Magne carefully noted the pregnancy of 429 sheep at the Al-

*Veterinary Obstetrics. Fleming, pp. 152 and 153. William R. Jenkins Co., N. Y.

fort Veterinary School during a period of eight years, with the following result:

2 instances of 143 days				-	57 instances of 150 days				
15	"	"	144	"	49	"	"	151	"
22	"	"	145	"	23	"	"	152	"
30	"	"	146	"	13	"	"	153	"
55	"	"	147	"	7	"	"	154	"
68	"	"	148	"	7	"	"	155	"
80	"	"	149	"	3	"	"	156	"

"From this list we observe that the difference between the longest and shortest period was only thirteen days, by far the largest number of births occurring between the 147th and 151st days; the shortest was 143 days and the longest 156 days. The average duration of pregnancy was about 149 days. Gestation was longer with the female than the male lambs, and this Magne attempts to explain by the greater development and weight of the former, which rendered parturition more difficult and slow.

"Colin says the average period in the sheep is 151 to 152 days, though parturition may take place from the 145th to the 160th day.

"Dieterichs gives the shortest period as 146 days, the longest 157—average 151 days; and Baumeister and Rueff state the shortest period in the sheep and goat as 135 days, the longest 160—average, 144 days; the male lambs requiring, as usual, the longest period. With regard to breed, these authorities found that the period of gestation in Merinos averaged 150.3 days; while with Southdowns it was only 144.2 days, or six days less.

"In the Merinos, for the male lamb the average period was 151.1 days, female lamb 150.6 days, and twins 149.9 days; and in the Southdowns, for the male lamb 144.7 days, female lamb 144.1, and twins 144 days.

"Magne asserts that the goat goes a little longer than the sheep, the average being five months and some days; another authority gives it as 148 days.

"The pig is usually pregnant four months, or according to some authorities three months, three weeks and three days. Baumeister and Rueff give the longest period as 130 days, the shortest 110—average, 120; while Dieterichs gives 109

days as the shortest and 133 as the longest—average, 115 to 116 days; and Magne says that it is rarely less than 109 or more than 120 days. Rainard noted the period of gestation in 65 pigs, and reports it to be as follows:

- 2 instances—104 days.
- 10 instances—110 to 115 days.
- 23 instances—116 to 120 days.
- 27 instances—121 to 125 days.
- 2 instances—126 days.
- 1 instance —127 days.

“The average was, therefore, 119 days, the interval between the longest and shortest periods being 23 days.”

In our experiments we have records of nineteen normal births in goats which show an average gestation period of 145 days. There was, however, considerable variation, as follows:

- 1 instance of 120 days.
- 1 instance of 129 days.
- 1 instance of 138 days.
- 1 instance of 143 days.
- 1 instance of 146 days.
- 14 instances of 147 to 152 days.

Records of twenty-seven goitrous births among goats shows the somewhat higher average gestation period of 161 days. There is also a greater variation, as follows:

- 1 instance of 130 days.
- 1 instance of 140 days.
- 4 instances of 145 to 150 days.
- 9 instances of 151 to 160 days.
- 5 instances of 161 to 170 days.
- 4 instances of 171 to 180 days.
- 1 instance of 183 days.
- 1 instance of 193 days.
- 1 instance of 196 days.

From the foregoing it is observed that the difference between the longest and shortest period of gestation in goats when giving birth to normal young was thirty-two days, while in the case of goitrous young it was sixty-six days. It is also evident that goats carrying goitrous young usually have a longer gestation period.

The same results did not obtain in the case of sheep and their gestation period was more uniform. Records of forty-five normal births show an average of 151 days; varying from

140 to 156 days, with one instance of 169 days. Records of eight goitrous births show an average period of 153 days, varying from 145 to 159 days.

The gestation period of our experimental sows showed only slight variation. Records of ninety-six normal births show an average period of 115 days. The variations were as follows:

- 1 instance of 102 days.
- 1 instance of 110 days.
- 1 instance of 111 days.
- 74 instances of 112 to 116 days.
- 16 instances of 117 to 120 days.
- 1 instance of 121 days.
- 1 instance of 124 days.
- 1 instance of 126 days.

The one sow which farrowed three successive litters of hairless pigs showed gestation periods of 121, 109 and 115 days respectively. Her last litter which, was normal, was farrowed after a gestation period of 124 days.

SUMMARY

Hyperplastic goitre is enzootic among all species of domestic animals in certain so-called goitrous regions. It is especially prevalent in certain sections of Washington, Montana, and British Columbia.

The disease is manifested in somewhat different forms in the different species of domestic animals, but the primary lesion in all cases is of similar character and consists of hyperplasia of the thyroid.

This type of goitre is of little importance in the adult, but causes grave disturbances in the newborn. Affected colts, kids, lambs, and pigs seldom live, while the condition is less fatal to affected calves.

It has not been definitely proved, but it is quite likely that a deficiency of iodine in the water, feed and possibly the soil is responsible for the malady. Other unknown factors may also be considered as causal agents.

Feeding experiments indicate that either water, feed or both from a goitrous region may cause goitre.

Perfectly controlled experiments with Angora goats show that goitre can be absolutely prevented by administering iodine to does during pregnancy. This can be given either in the form of potassium iodide per orem or tincture of iodine subcutaneously or on the unbroken skin.

Field experiments also indicate that the condition can be successfully prevented in other species of animals by the use of iodine.

EXPLANATION OF FIGURES

The following illustrations are from original photographs taken by the author during the investigation of goitre and associated conditions in domestic animals.

Fig. 1—A weak colt twenty-four hours old. It seems well developed physically, but is so weak as to be unable to support the head without resting the nose on the ground.

Fig. 2—A six-weeks-old weak colt. Occasionally a colt of this type lives, but remains a permanent cripple. At four years of age this animal was practically worthless because of the deformity of the legs.

Fig. 3—A typical stillborn goitrous calf—one of a pair of twins. The swelling in the thyroid region and the absence of hair over the greater part of the body may be noted. Hairlessness is not common in calves, but occasionally occurs.

Fig. 4—Goitrous calf six weeks old. Many calves in goitrous regions show enlargement of the thyroids but appear otherwise to be in normal health.

Fig. 5—A typical live newborn hairless pig. The thickened, wrinkled, pulpy skin may be noted.

Fig. 6—A typical case of goitre in an adult Angora doe.

Fig. 7—A typical pair of stillborn goitrous Angora twins. The size of the thyroids and the complete absence of hair may be noted.

Fig. 8—Another pair of stillborn goitrous Angora twins. In this instance the bodies are well covered with normal hair.

Fig. 9—A pair of normal Angora twins. The doe which gave birth to these was treated during her gestation period with five mils of a ten per cent solution of tincture of iodine subcutaneously once a week. The previous year, without treatment, she gave birth to the kids shown in Fig. 7.

Fig. 10—Thyroid of a normal hog. The uniform distribution and size of the follicles and the presence of colloid may be noted. x 125.

Fig. 11.—Normal thyroid of a chicken. This resembles the normal thyroid of mammals. The follicles are quite uniform in size and are filled with colloid. The long tortuous tube in the center is a vessel filled with blood. x 125.

Fig. 12—Normal thyroid of a cow. The orderly arrangement of follicles, the simple columnar cells lining them and the presence of colloid should be noted. x 125.

Fig. 13—Normal thyroid of a lamb. Follicles well filled with colloid and lined by simple cuboidal epithelium. x 125.

Fig. 14—The same as Fig. 12, more highly magnified. This shows the lining epithelium. x 500.

Fig. 15—Same as Fig. 13, more highly magnified. x 500.

Fig. 16—Thyroid of a newborn weak colt. The multitude of small tubules lined by simple cuboidal epithelium may be noted. This field shows a total absence of colloid, but a few of these tubules in the entire section show the presence of this material. x 125.

Fig. 17—This is the same as Fig. 16, more highly magnified. The small tubules, with their lining epithelium, are here seen. x 500.

Fig. 18—Section of thyroid of a newborn goitrous calf. The pronounced congestion at A may be noted. Outside of the vessel there is an abundance of hemorrhagic extravasate represented by the lighter areas. Follicles are entirely absent. The darker spots mixed in with the extravasate are follicle cells. x 125.

Fig. 19—A highly magnified portion of the specimen shown in Fig. 18. The non-nucleated cells are red blood corpuscles; some are within capillaries, while others are extravasated. The darker nucleated cells are follicle epithelium lying singly and in groups.

Fig. 20—Thyroid of a six-weeks-old goitre calf. The hemorrhagic extravasate has been entirely absorbed and the congestion has materially subsided. There is formation of new follicles, most of which are very large in size and irregular in shape; they show an infolding of the stroma and epithelial lining. The lumen is open and contains a serous material. There is one small apparently normal follicle at A showing colloid. x 125.

Fig. 21—A more highly magnified portion of the preceding. The papillary projection in the follicle and the serous material in the lumen may be noted. There is still slight congestion

in the capillaries in the wall. The epithelium is distinctly columnar. x 500.

Fig. 22—Thyroid of a hairless pig. In this specimen the tubules are widely separated and irregular in shape, but small. The space between the tubules is filled with serum, leukocytes, fibroblasts, extravasated blood and exfoliated follicle cells. There is a complete absence of colloid. x 125.

Fig. 23—A more highly magnified portion of the specimen shown in Fig. 22. x 500.

Fig. 24—Thyroid of a goitrous lamb. The follicles are variable in size, on the whole, smaller than normal. The lining epithelium is of the simple columnar type and there is a complete absence of colloid. x 125.

Fig. 25—Thyroid of a goitrous lamb. The change in this thyroid is slightly different from that seen in Fig. 24. The follicles are irregular in shape and on the whole considerably larger than normal. There are several layers of columnar cells lining the follicles; many of the cells are exfoliated and lie free in the lumen. There is a complete absence of colloid. x 125.

Fig. 26—A portion of the same specimen as shown in Fig. 24; more highly magnified. The columnar epithelium and the absence of colloid may be noted. x 500.

Fig. 27—A more highly magnified portion of Fig 25, showing a section of only one follicle. The exfoliated cells lying free in the lumen may be noted. x 500.

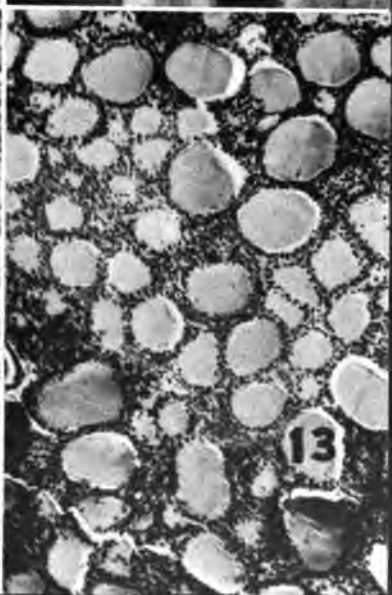
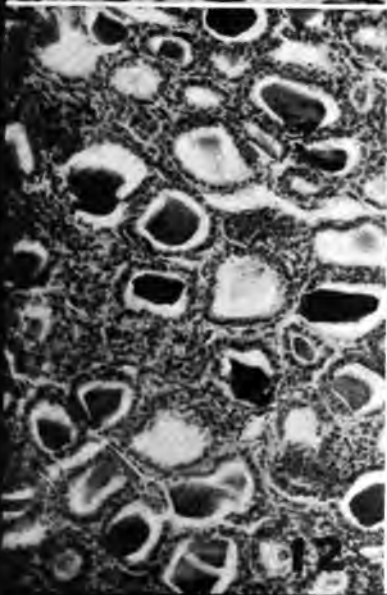
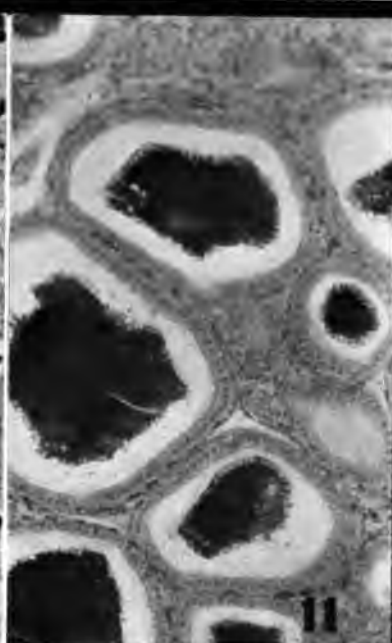
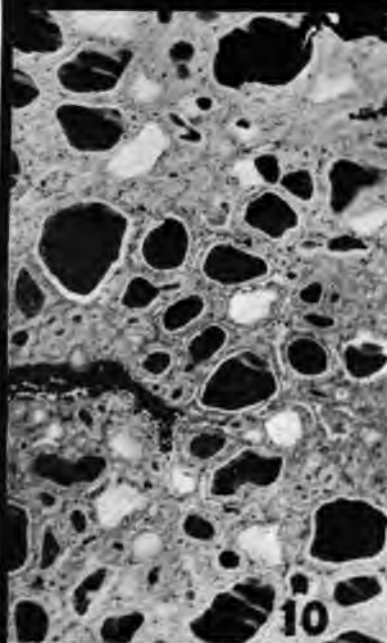
Fig. 28—Section of the wall of two adjoining follicles in the thyroid of a sow which farrowed hairless pigs. The several layers of follicle cells and the presence of a mitrotic figure near the lumen may be noted. The lighter staining mass in the lumen is serous material. x 500.

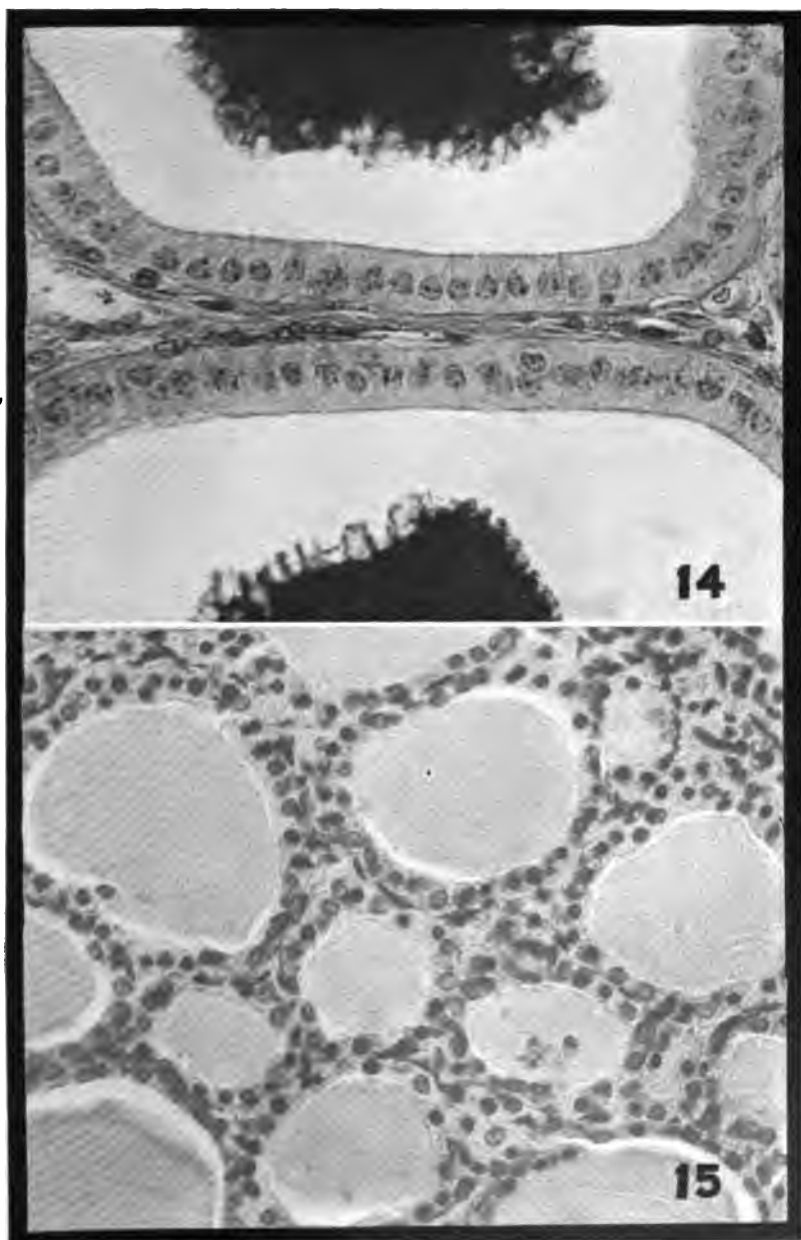
Fig. 29—Thyroid of an adult chicken affected with goitre. The large number of small tubules showing absence of colloid may be noted. A few apparently normal follicles with colloid are also present. A vessel filled with blood is seen at one edge. x 125.

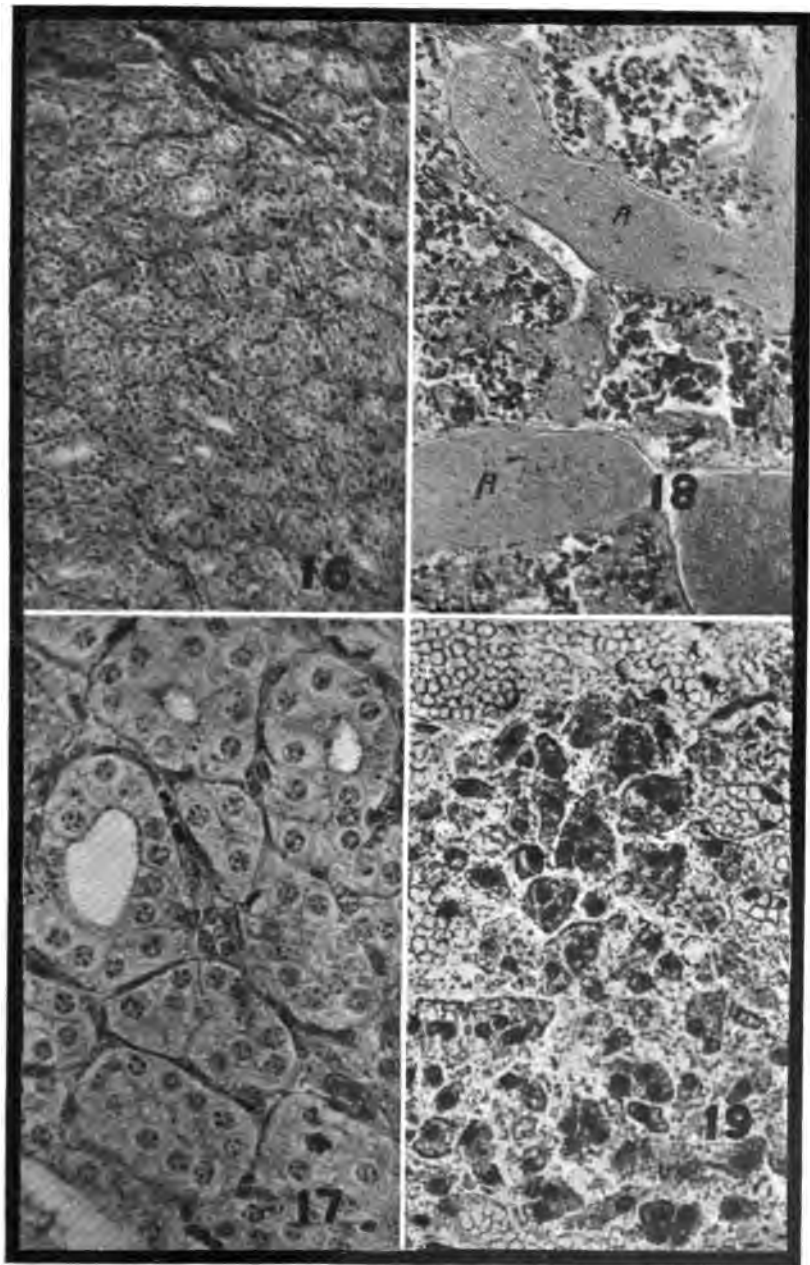


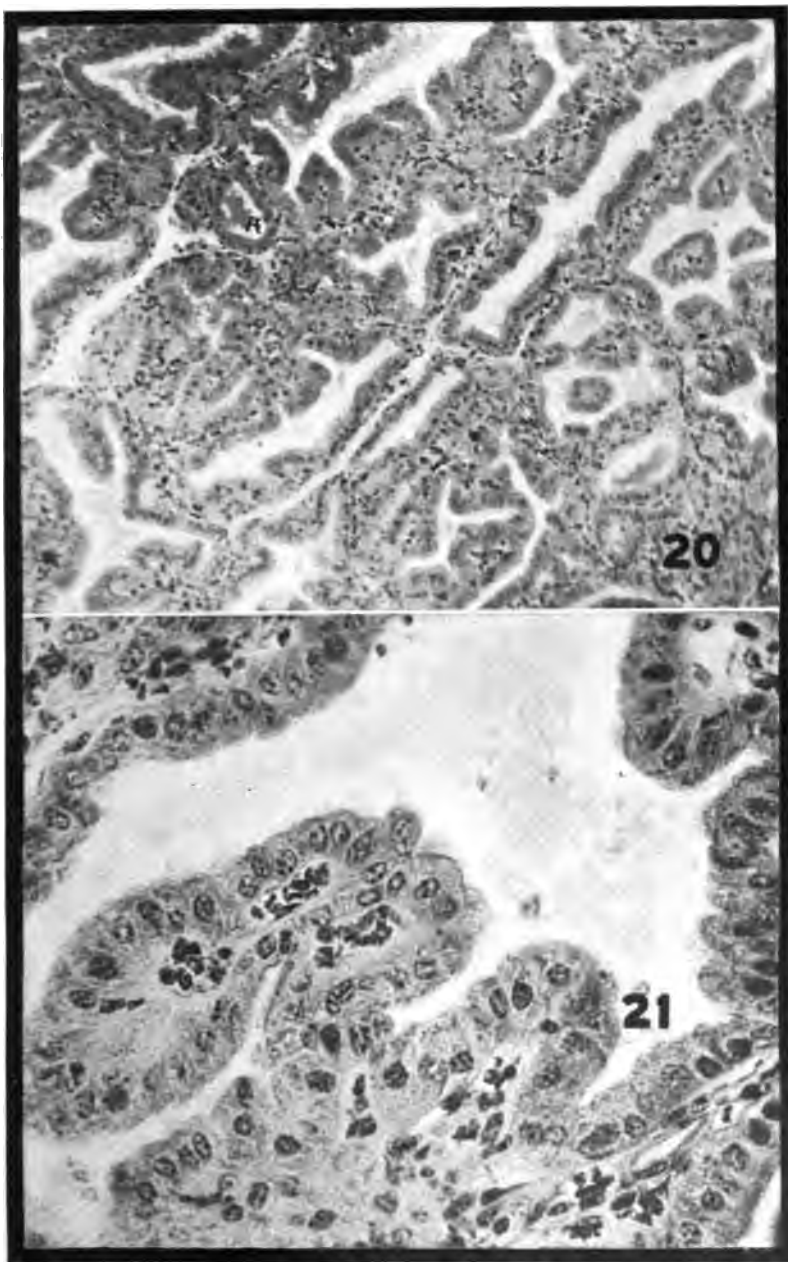


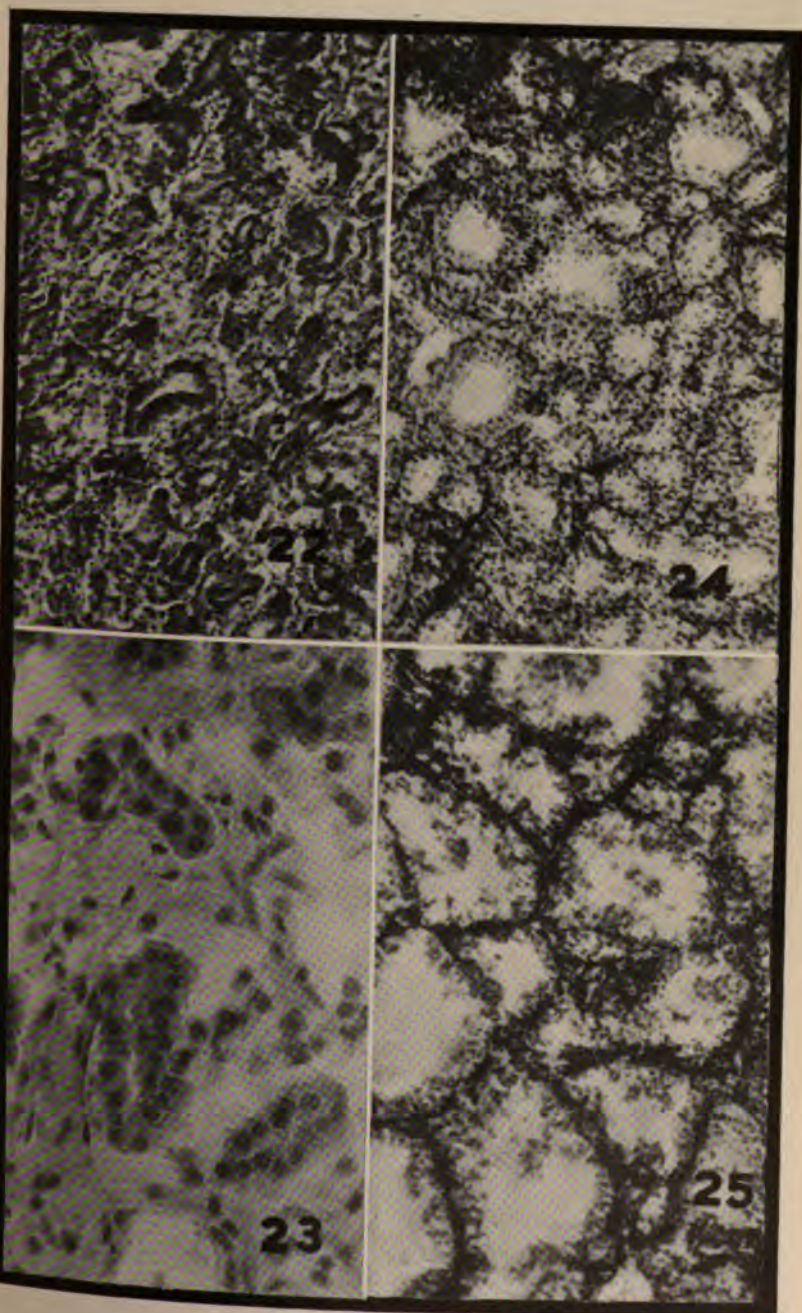


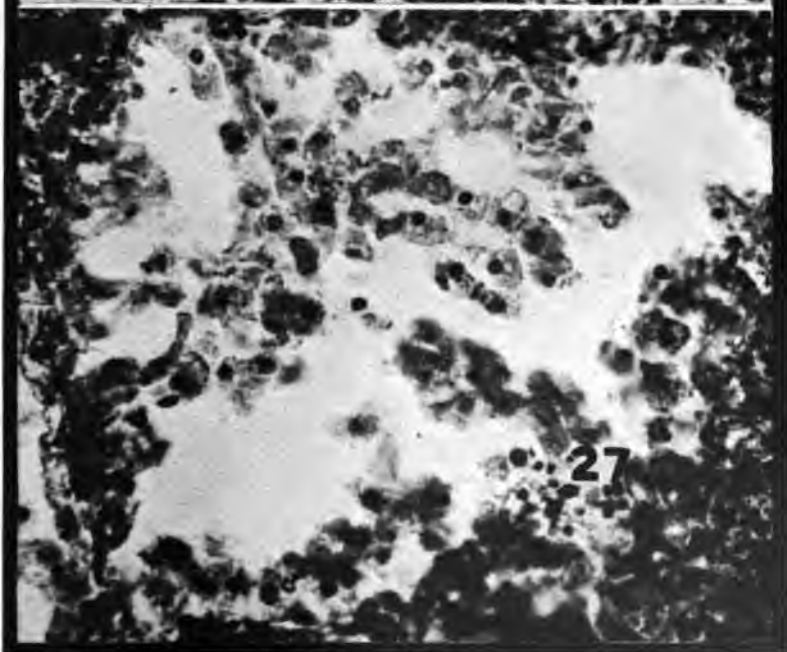
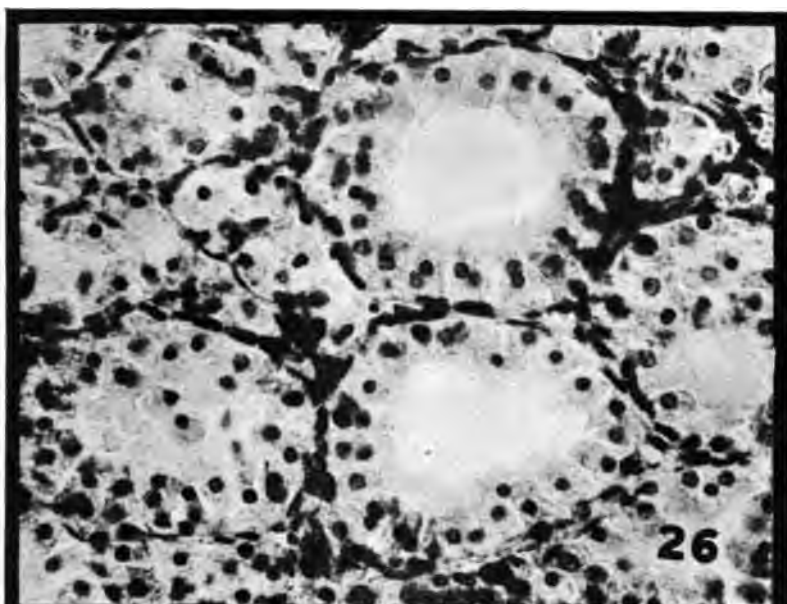


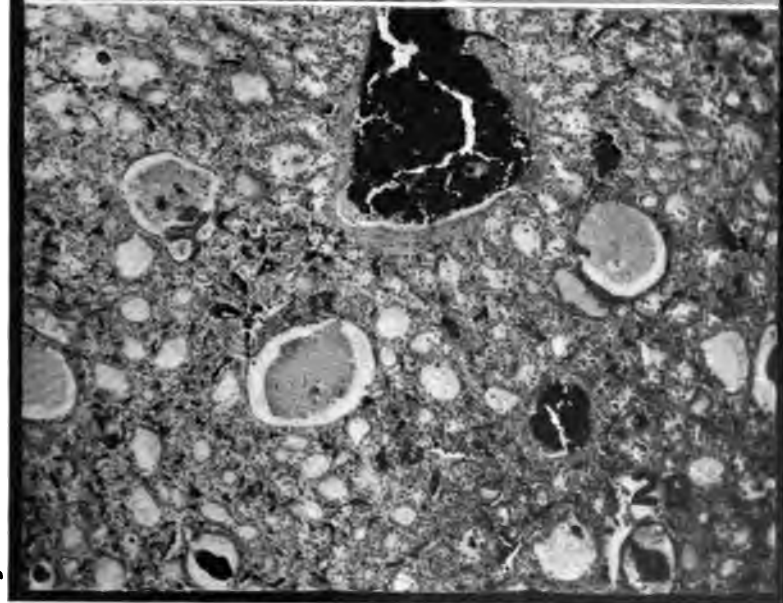
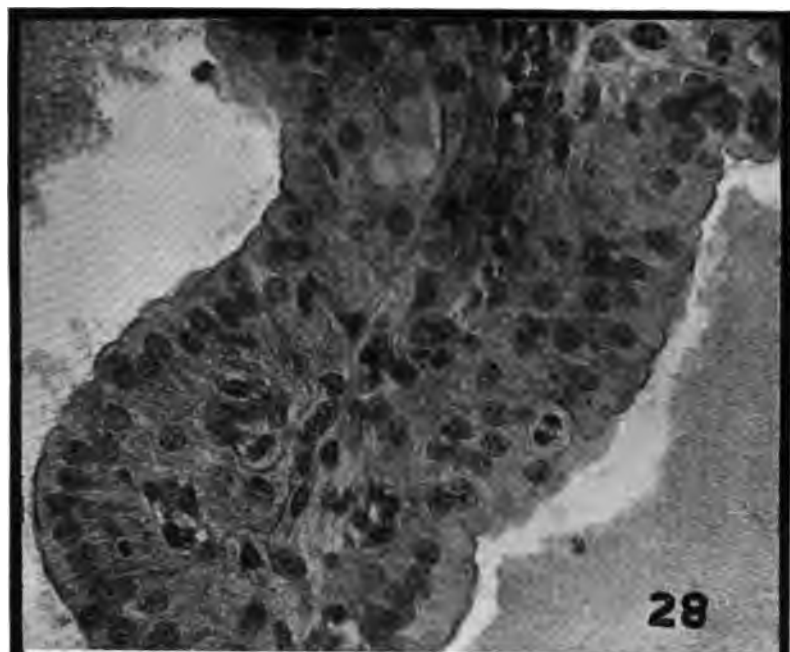












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STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISION OF ANIMAL HUSBANDRY

Pea Straw for Fattening Beef Cattle

By

H. HACKEDORN and J. SOTOLA



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Pea Straw for Fattening Beef Cattle

By H. HACKEDORN and J. SOTOLA

INTRODUCTION

Peas are grown in many sections of Eastern Washington in place of fallowing the land during the summer. At present the pea growing area is confined to those sections of the State where the rainfall exceeds 16 to 18 inches.

Much of the crop is grown for seed purposes and after harvesting and threshing a considerable amount of pea straw remains. The straw has been used as a feed for cattle, sheep and horses for a number of years. Opinions differ widely as to its value as a feed, for which reason the Washington Experimental Station undertook to obtain some accurate information in regard to pea straw as a roughage for beef cattle. The following preliminary report is offered at this time with the hope that it may be of some service to the cattle men in the State. **Definite conclusions, however, cannot be drawn from the limited amount of data available.**

This experiment was planned with the view of obtaining reliable data, bearing on the digestibility and feeding value of pea straw for fattening steers and stressing direct comparisons with alfalfa hay and corn silage.

In calculating the rations, when planning this experiment, it became apparent that the digestibility of Pea Straw had not heretofore been determined directly. For this reason a digestion trial with Pea Straw was planned to accompany the feeding tests.

Part I contains a discussion and definition of terms, which seem essential to a clear understanding of the methods employed and application of results obtained, in these trials.

PART I

DIGESTION TRIALS

Discussion of Feeds

Plants and animals consist of chemical elements. These elements do not exist separately but as the letters of the alphabet are combined to form words of numerous languages, so the elements occur in combinations forming myriads of compounds. For convenience these compounds are divided into five classes, namely (1) water, (2) crude protein, (3) carbohydrates which include crude fiber and nitrogen free extract, (4) fats and (5) ash.

These classes of compounds are called nutrients. Any feed constituents which liberate energy in the animal body or have influence on tissue formation or in any way aid in supporting life of animals may be classed as nutrients. They are carriers of energy. The green plants transform the radiant energy of the sun into chemical energy of their constituents—which is yielded later to the animal organism.

Proteins and carbohydrates have almost equal energy values. Fats appear to be more concentrated, supplying about $2\frac{1}{4}$ times as much energy as either one of the other two.

The feed supplies specific materials required for building and repairing all the complex structures of the body. It also supplies compounds necessary to the harmonious work of these structures. The proteins, fats, and ash, which make up the largest share of the animal body, have come originally from the feed substances. The protein of feeds, although used for other purposes, contributes largely to the building up of muscles. Fats and carbohydrates and even proteins of feeds may finally appear as fat in the storage tissues, while the ash ingredients in turn may be deposited in bones of the animal body.

A comparison of barley, corn silage, and the straws, with meat and milk, convinces one that marked changes are necessary to convert one group into the other. The first step in such a change is the process of digestion. All food, before it

can function in either one of the roles already suggested, must undergo this process.

Even under the most favorable conditions all feed is not digested. The degree of digestibility varies. Straws are less digestible than grains. Straws have a high content of woody tissues known as fiber. At present no enzymes secreted by the animal body are known to digest it. Such fiber may inclose other more easily digestible nutrients, thus preventing their digestion.

The crude fiber of feeds is supposedly broken down by bacteria in the animal body. The work of the bacteria is assisted by proteins in the feed.* Proteins also stimulate secretion of digestive fluids. Because of these two factors, as well as others which will not be discussed, the amount of protein and crude fiber in a feed is used as an index of its digestibility. The ratio of protein to the sum of the carbohydrates and two and a quarter times the fats is known as the **Nutritive Ratio**. Fats are multiplied by this factor because of their higher energy content.

Digestibility of feeds is generally measured by the amount of the nutrients of those feeds retained by animals. If 6 lbs. of protein are fed and 2 lbs. appear in the feces, it is evident that only 4 lbs. were retained. The digestibility of protein in this case is $\frac{4}{6}$, or 66% per cent. Digestibility is expressed by a term known as the "Coefficient of Digestibility." Instead of the above protein being 66% per cent digestible it is customary to say that its coefficient of digestibility is 66%.

It is evident that the indigestible portion of a feed can make no contribution to the animal body. Two feeds which are equally digested need not be of the same value to the animal, because the digested matter of one may be used to the better advantage by the body.

In comparing new feeds with other feeds, the first step is to determine as accurately as possible what proportion of each ingredient is capable of digestion, that is, it becomes necessary to determine the coefficients of digestibility of the various nutrients in those feeds. This is determined by trial with

*"Nutrition of Farm Animals," Armsby, p. 621.

animals. Coefficients for pea straw have not heretofore been determined or else not published by other Experiment Stations.

Methods Used in Digestion Trials

A digestion trial aims to measure the amount of feed fed and the amount of undigested feed excreted. The nutrients which disappear in the passage through the alimentary tract are assumed to be digested. It is evident that to measure the absorbed substances directly is beyond present day technique.

The error in such trials lies in the assumption that feces consist only of undigested feed. They include excretory products as well. In herbivorous animals the proportion of these to total feces is small and they are disregarded.

A digestion trial must be preceded by a preliminary period in which the feed later to be tested is fed regularly in weighed quantities as in the experiment. The preliminary period aims to remove previous feeds from the digestive tract and to establish uniform defecation. In ruminants the preliminary period must be made longer than for other classes of animals, that is, at least of one to two weeks duration. The experiment proper usually extends over a period of 10 days.

Discussion of the Digestion Trials

A grade Shorthorn and a grade Hereford steer both over two years of age, weighing 882 and 910 lbs. at the time of purchase were gradually put on an exclusive pea straw ration. The amount of pea straw consumed daily, fluctuated at first but soon reached $16\frac{1}{2}$ lbs. per day. The steers were confined in stanchion stalls, the stanchions being connected to walls of stalls by canvass. This arrangement prevented waste of feed and facilitated an accurate measure of feed consumed and refused. The stanchions prevented the steers from eating their bedding, which consisted of wheat straw.

The steers were fed and watered regularly three times a day, $5\frac{1}{2}$ lbs. of pea straw being given them at each feed. The refused feed was air dried before weighing. All refused pea straw was sampled for chemical analysis. With each noon

feed the steers were given $2\frac{1}{2}$ oz. of salt per head. They were exercised daily.

Good sound pea straw, from the same shipment as was used in the feeding test, was passed through a silage cutter, enough being so treated to supply uniform feed for the digestion trial inclusive of the preliminary period.

It is customary in digestion experiments to cut all coarse feed. This insures easy handling, gives a more accurate check on refused feed, and makes sampling very easy.

Fluctuations in humidity from day to day affect the moisture content of a feed like pea straw. This would seem to necessitate daily sampling of the feed. To avoid this the pea straw to be fed during the ten day experimental period was weighed out at one time and put into sealed paper sacks. Each sack then represented the same amount of dry matter irrespective of a fluctuating humidity during the ten day period. The pea straw was carefully sampled for chemical analysis as the sacks were filled.

The preliminary period, 32 days, was more than sufficient to remove any previous feeds from the alimentary tract. **The animals were well accustomed to their feed when the trial proper began.** They neither lost nor gained in weight during the ten day test. The feces were collected quantitatively. They were weighed every 24 hours and after a thorough mixing were carefully sampled for chemical analysis. Large air tight cans prevented evaporation of moisture from feces between sampling periods.

All the chemical analyses of the feed and the feces were made by the junior author according to the methods proposed in Bulletin 107 of the Bureau of Chemistry, entitled "Official and Provisional Methods of Analysis."

During the preliminary feeding period the steers were weighed every 10 days. At the beginning of the digestion trial proper daily weights of the steers were recorded.

Tables I, II and III are summaries of the numerous analyses made of feeds and feces collected during the ten day digestion trials with two steers.

TABLE I
Summary of Ten-Day Digestion Trial
STEER I

	Grams.....	Dry Matter, Grams.....	Crude Protein, Grams.....	Crude Fat, Grams.....	Crude Fibre, Grams.....	N. F. Ext., Grams.....	Ash, Grams.....	Organic Matter, Grams.....
Pea Straw Fed	75,000.0	67,657.5	4,537.5	1,177.5	24,930.0	33,022.5	3,990.0	63,667.5
Pea Straw Refused	647.7	578.6	42.2	8.7	182.5	252.9	92.3	486.3
Total Pea Straw Consumed	74,352.3	67,078.9	4,495.3	1,168.8	24,747.5	32,769.6	3,897.7	63,171.2
Feces	172,389.0	26,805.0	1,960.4	572.3	10,717.9	10,600.9	2,851.2	23,953.2
Total Digested		40,273.9	2,534.9	596.5	14,029.6	22,168.7	1,046.5	39,228.0
Percent- age Di- gestibil- ity		60.0	56.4	51.0	56.7	67.7	26.9	62.1

Table I shows the coefficient of digestibility of crude protein in pea straw for Steer I to be 56.4. Out of every 100 lbs. of protein in pea straw fed, 56.4 lbs. were digested.

TABLE II
Summary of Ten-Day Digestion Trial
STEER II

	Grams.....	Dry Matter, Grams.....	Crude Protein, Grams.....	Crude Fat, Grams.....	Crude Fibre, Grams.....	N. F. Ext., Grams.....	Ash, Grams.....	Organic Matter, Grams.....
Pea Straw Fed	75,000.0	67,657.5	4,537.5	1,177.5	24,930.0	33,022.5	3,990.0	63,667.5
Pea Straw Refused	288.7	213.2	16.2	3.6	88.8	91.3	13.3	199.9
Total Pea Straw Consumed	74,711.3	67,444.3	4,521.3	1,173.9	24,841.2	32,931.2	3,976.7	63,467.6
Feces	169,953.0	27,955.0	1,788.6	649.2	11,222.7	10,966.1	3,134.7	24,820.3
Total Digested		39,489.3	2,732.7	524.7	13,618.5	21,965.1	842.0	38,647.3
Percent- age Di- gestibil- ity		58.6	60.4	44.7	54.8	66.7	21.7	60.9

By comparing the last lines of Tables I and II the difference in digestibility of the same feed when fed to two different steers is brought out. In no single instance, however, are there very marked variations. The differences which do exist are suggestive of the desirability of conducting digestion trials with a large number of animals.

TABLE III
Coefficients of Digestibility of Pea Straw

	Dry Matter..	Crude Protein..	Crude Fat.....	Crude Fiber...	N. F. Ext..	* Ash.....	Organic Matter..
I	60.0	56.4	51.0	56.7	67.7	26.9	62.1
II	58.6	60.4	44.7	54.8	66.7	21.2	60.9
Av. two trials ...	59.3	58.4	47.8	55.8	67.2	24.1	61.5

The coefficient of digestibility for protein of alfalfa hay as reported by Henry and Morrison is 71. The digestibility of crude protein in pea straw is thus seen to be less than of crude protein in alfalfa hay, the average coefficient in this case being 58.4.

Pounds of Nutrients per 100 Pounds Feed

	Water....	Dry Matter..	Protein...	Fat.....	Crude Fiber...	N. F. Ext..	Ash.....	Organic Matter..
Pea Straw Av. 20 Analyses	9.79	90.21	6.05	1.57	33.24	44.03	5.32	84.89

Digestible Nutrients per 100 Pounds Pea Straw

	Protein...	Fat.....	Crude Fiber...	N. F. Ext..	Ash.....	Organic Matter..	Nutritive Ratio...
Pea Straw	3.53	.75	18.55	29.59	1.28	52.2	14.1

*Not much significance is attached to digestible ash because a high percentage of ash is excreted through the large intestine and it masks digestibility.

It is of interest to note that the two steers used in the digestion trial were fed 16½ lbs. of pea straw per head daily for 60 days. During this time one steer lost 6 lbs., and the other 9 lbs. Since the body weight of steers fluctuates more than this every day, it is safe to conclude that the steers practically maintained their weight.



Fig 1.—Steer I. Photograph taken after completion of digestion trial.

Summary of digestion trial with steer I is reported in Table I.



Fig. 2.—Steer II. Photograph taken after completion of digestion trial. Summary of digestion trial with steer II is reported in Table II.

PART II

THE FEEDING TEST

General Plan of Feeding Test

A comparison of feeds when fed at the point of their greatest efficiency is more accurate than a comparison of similar feeds fed in unbalanced rations. It is readily apparent that the steers receiving alfalfa hay would have consumed a larger quantity than was given them, but such a ration would not have been balanced sufficiently to permit as accurate comparison with other lots, where balanced rations were fed. The grain ration was kept constant in order to eliminate as many varying factors in the experiment as possible, and so as to bring out comparisons of roughages. Further in order to permit fairly accurate comparisons of the roughages, it was planned to feed all lots so that each lot would receive an equivalent amount of digestible nutrients. Since pea straw is the feed being investigated, the pea straw lot was used as the base lot.

Lots:—The rations to be fed the various lots were planned as follows:

Lot I—Grain 16 lbs.; Pea Straw—all the steers would consume without waste (Preliminary trials showed the maximum quantity to be about 20 lbs. per head.)

Lot II—Grain 16 lbs.; Alfalfa hay fed in limited quantity to supply approximately the same quantity of digestible nutrients as any of the other rations (13 lbs.)

Lot III—Grain 16 lbs.; Pea straw fed at the rate of one-half the quantity received by Lot I (10 lbs.) and alfalfa hay at the rate of one-half the quantity fed Lot II (6½ lbs.)

Lot IV—Grain 16 lbs.; Pea Straw at the rate of one-half the quantity fed Lot I (10 lbs.) and all the corn silage the steers would eat without undue waste (about 21 lbs.)

The first two lots afford a direct comparison of pea straw and alfalfa hay. Lots I and IV bring out the relation of pea straw to silage. Lots I and III give a check upon the comparisons obtained from Lots I and II. Lots III and IV give comparisons of alfalfa and silage. The various lots also afford

interesting suggestions as to the methods of utilizing pea straw.

Cattle Used in the Test

The steers used in this test were purchased November 8, 1919, at the Union Stock Yards of Spokane, Washington, and fed at the Experiment Station, Pullman, Washington.

They were high grade Shorthorn steers. As feeder cattle they graded from good to choice, and were fairly uniform in size and quality. The variations in weight between lightest and heaviest individual did not exceed two hundred pounds. (See illustrations Figs. III, IV, V and VI). The steers were calved in the spring of 1917 and were selected out of a herd of three hundred steers, running on a mountain range, in Kittitas County. They were the third prize carload of two-year feeder steers at the Western Royal Livestock Show.

At the time of purchase the average weight was 1,002.1 lbs. Their cost was \$10.00 per 100 pounds.

Quarters

The steers were fed in a shed situated at the top of a gentle slope with a southern exposure. Each lot was twenty-five feet wide and fifty-four feet deep, including feed rack space. The upper fifth of each lot was under cover, enclosed on three sides but open on the south side.



Fig. 3.—Illustrating type of cattle receiving pea straw as sole roughage. (Lot I.)



Fig. 4.—Illustrating type of cattle receiving alfalfa hay as sole roughage. (Lot II.)



Fig. 5.—Illustrating type of cattle receiving alfalfa hay and pea straw. (Lot III.)



Fig. 6.—Illustrating type of cattle receiving pea straw and silage as roughage. (Lot IV.)

The shed space amounted to about 1200 square feet. The floor of the shed and all of the lots were unpaved. The lots became very muddy during the late fall and early winter and remained in bad condition except during most of the months of December and January when the ground was frozen.

The feed racks were under cover, but the water troughs were not.

Feeds Used

The pea straw was of very good quality. It contained very few coarse stems and was free of other plants. It came from a variety known as the Alaska Pea. The straw contained a few light and immature peas, which were blown out with the straw during threshing.

The alfalfa used during the first and last thirty day periods was of good quality; however, it was somewhat stemmy during the second period.

The silage was made from corn produced on the College Farm. The yield of green feed per acre was approximately six tons.

Chemical analyses of all feeds used were made and the results of the average of all analyses are given in Table IV. The samples of the feeds were taken each week except in the case of corn silage, which feed was sampled daily.

TABLE IV
Chemical Analyses of Feeds

	Percent Moisture...	Percent Protein...	Percent Crude Fiber...	Percent N. F. Ext.	Percent Ether Ext.	Percent Ash.....
Ground Barley	11.06	9.32	6.41	68.71	1.84	2.67
C. Seed Meal	9.60	40.73	14.14	24.60	5.77	5.17
Pea Straw	9.79	6.05	33.24	44.03	1.57	5.32
Silage	71.60	1.99	5.94	17.57	.91	1.98
Alfalfa Hay	10.79	11.67	40.00	30.21	1.15	6.00

Table V was compiled by using the figures in Table IV and the coefficients of digestion as given in "Feeds and Feeding"

by Henry and Morrison, for all feeds except pea straw. The factors derived in connection with this feeding test were used with the last named feed.

TABLE V
Digestible Nutrients in Feeds

	Total Dry Matter.....	Digestible Nutri- ents per 100 lbs. Lbs. Protein....	Total Diges- Nutrient.	Nutritive Ratio.....
Ground Barley	88.94	7.27	70.05	8.6
C. Seed Meal	90.40	34.21	63.37	85
Pea Straw	90.21	3.53	53.36	14.1
Silage	28.40	1.00	18.13	17.1
Alfalfa Hay	80.03	8.29	47.68	4.7

The average daily ration per steer in the four Lots for the entire experimental period may be found in Table VI.

Table VI shows the quantity of protein, total digestible nutrients and nutritive ratio in the average rations of each lot. The requirements for a 1020 pound steer (average weight of steers for experimental period) as expressed in the latter part of this table, show the rations to be fairly well balanced. The ration of Lot IV contains the largest amount of protein but the smallest amount of digestible nutrients.

The average daily gains of the steers receiving the different rations for 95 days varied from 2.53 lbs. to 2.70 lbs., the higher figure representing gains made by the steers in Lot II.

TABLE VI

Average Rations Fed Each Lot During Feeding Test

	Lbs. Feed.....	Dry Substance..	Diges. Crude Prot.....	Total Diges. Nut.....	Nutritive Ratio.....
Lot I					
*Grain Mix.	15.06	13.42	1.60	10.42	
Pea Straw	18.96	8.08	.67	10.15	
Total	34.02	21.50	2.27	20.57	8.0
Lot II					
*Grain Mix.	15.07	13.42	1.60	10.42	
Alfalfa Hay	14.74	13.12	1.22	7.03	
Total	29.81	26.54	2.82	17.45	5.2
Lot III					
*Grain Mix.	15.07	13.42	1.60	10.42	
Pea Straw	9.90	8.93	.34	5.28	
Alfalfa Hay	7.34	6.54	.61	3.20	
Total	32.31	28.89	2.55	18.90	6.6
Lot IV					
*Grain Mix.	15.18	13.42	1.60	10.42	
Pea Straw	8.67	7.82	.30	4.63	
Corn Silage	20.88	5.93	.21	3.79	
Total	44.73	27.17	2.11	18.84	7.9
Modified Wolff-Lehmann Standard					
For 1020 lb. Steer	22.4-25.51	2.04-2.35	18.36	7.07	

*The grain mixture in all cases consisted of seven parts of steam rolled barley and one part choice cottonseed meal by weight.

Records and Weights

All steers were given individual numbers and each steer was weighed separately. The initial and final weights of the experimental period were the averages of three consecutive daily weights. The middle date of each succession was the basal date for the beginning and the end of the experiment.

Individual weights of steers at thirty day intervals were also recorded. All weighings were made under the same conditions in respect to previous feeding and watering.

All steers were weighed before receiving the morning feed, and did not have access to water from 6 p. m. on the day preceding the weighing, until after weighing.

The feeds were weighed before each feeding.

Accurate and detailed records were made daily of all weights, of feed fed and feed refused.

Pigs in Feed Lots

A pig weighing between 90 and 100 pounds was placed in each lot of six steers. All four pigs, for the entire feeding period, gained only 16 pounds. For this reason returns from pigs will not be considered in the following pages.

Methods of Feeding

The cattle were fed regularly at 7 a. m. and 5 p. m.

The steers were started on four pounds of a 7 to 1 mixture of steam rolled barley and cotton seed meal. The grain mixture was increased one pound daily until the amount reached ten pounds per head. From then on, a pound of mixture per head was added every third day till the desired amount was reached (16 lbs. per head daily). The amount of roughage consumed was fairly large at first. It decreased gradually as the grain ration was increased.

The steers were gotten on a full feed of grain without a single case of scouring. They remained in excellent health throughout the feeding test, as indicated by their glossy coats and good appetites.

The grain was fed first. After it had been cleaned up the roughages were fed. The grain was always thoroughly cleaned up, hence the feed refused consisted of roughage. When two roughages were fed the same lot, the refuse was credited to the two roughages in the same proportions in which they were fed.

The steers had free access to salt and water at all times, except twelve hours before every weighing.

The Measure of Efficiency

The efficiency of a feed for fattening steers from the practical point of view is measured by the quantity of the feed needed per unit of gain, by the degree of finish it will produce, and by the cost of the feed. One feed, although lower

priced per pound than another, may be so much less efficient in producing gains and finish that it may prove an expensive one to use.

The degree of finish in all four lots was very uniform at the time the experiment closed, so that the difference in the comparison of the feed consumed to produce 100 pounds of gain in this particular experiment would represent the relative value of various roughages. A summary of results of the feeding test is presented in Table VII.

TABLE VII
Summary of Weight Gains and Feed Consumed, Average per Head

	Lot I— Pea Straw...	Lot II— Alfalfa Hay...	Lot III— Pea Straw Alfalfa Hay...	Lot IV— Pea Straw Corn Silage...
Wt. in Feed Lot (Pullman) Nov. 25, 1919 (inclusive) ..	950.5	950.7	959.1	956.8
Wt. in Feed Lot, Feb. 27, 1920 (inclusive)...	1,190.7	1,196.3	1,202.3	1,213.7
Total Gain in Feed Lot, 95 days	240.2	245.6	243.2	256.9
Daily Gain in Feed Lot	2.53	2.59	2.56	2.70
DAILY RATION:				
*Grain { Total	15.07	15.07	15.07	15.07
Barley	13.19	13.19	13.19	13.19
C. S. M.	1.88	1.88	1.88	1.88
Pea Straw	19.55	.....	9.90	8.82
Alfalfa .....	.....	14.74	7.34	.....
Corn Silage .....	.....	.....	.....	20.81
Feed per 100 lbs. body gain				
Grain { Total	595.75	583.05	588.81	557.80
Barley	521.23	510.17	515.21	488.01
C. S. M.	74.52	72.88	73.60	69.79
Pea Straw	773.11	.....	386.92	326.19
Alfalfa .....	.....	570.44	287.01	.....
Corn Silage .....	.....	.....	.....	769.56
COST OF 100 LBS. BODY GAIN:				
Grain { Barley	\$16.41	\$16.07	\$16.22	\$15.37
C. S. M.	2.98	2.91	2.94	2.79
Pea Straw	5.64	.....	2.90	2.44
Alfalfa .....	.....	7.98	4.01	.....
Corn Silage .....	.....	.....	.....	3.84
Total	\$25.03	\$26.96	\$26.07	24.44

*Barley, steam rolled, \$63 per T.; Pea Straw, \$15 per T., baled; Alfalfa, \$28 per T., baled; Corn Silage, \$10 per T.; Cottonseed Meal, \$80 per T.

It will be noticed in Table VII that Lot IV, receiving pea straw and corn silage as roughages required only 557.80 pounds of grain mixture per 100 pounds gain, which is somewhat less than that required by the other three lots.

Lot I, fed pea straw as the sole roughage, required 595.75 pounds of grain for the same amount of gain. A partial substitution of corn silage for pea straw reduced the grain requirement per 100 pounds of gain by 37.95 pounds or 6 per cent, which is not a wide variation, and is within the range of experimental error. Considering the roughages separate from the grain, it took 769.56 pounds of corn silage, 326.19 pounds of pea straw to replace 773.11 pounds of pea straw in the production of 100 pounds of gain. By subtracting, or eliminating the pea straw, 769.56 pounds of corn silage, fed with the above grain ration, had the replacing value of 346.92 pounds of pea straw. This reduced still further, shows 1 pound of pea straw to have the replacing value of 2.2 pounds of corn silage. The total cost of 100 pounds gain, however, with the prevailing prices, was less for Lot IV, the silage lot, than for Lot I, the pea straw lot.

Lots I and II afford an interesting comparison. The average initial weight of the steers in these two lots was 950.50 pounds and 950.70 pounds, respectively. The average weights at the conclusion of the experiment were 1190.70 pounds and 1196.30 pounds respectively. Hence, the rate of gain was practically the same. Lot I receiving pea straw as the sole roughage, required 595.75 pounds of grain per 100 pounds body gain. Lot II, receiving alfalfa hay alone, required 583.05 pounds for the same gain. The difference in the quantity of grain required to produce a unit of gain was only two per cent. So it may be said that the grain requirement, to produce 100 pounds of gain in the two lots was practically identical. It follows that the total roughages fed the two lots must have been equivalent in their ability to produce body gain. By comparing the roughages separately from the grain, it is seen that 570.44 pounds of alfalfa was replaced by 773.11 pounds of pea straw, or that 1 pound of alfalfa was replaced by 1.36 pounds of pea straw in these specific rations. From these

figures pea straw is worth 75% as much as alfalfa in feeding value. If alfalfa hay is valued at \$28 a ton, pea straw from this relation would be valued at \$20.75 a ton. The prevailing prices of feed, however, made the cost of 100 pounds gain in a lot receiving alfalfa, approximately \$2 higher than the lot which was fed pea straw. It should be noted here, however, that the lot of steers fed alfalfa hay sold for twenty-five cents more per 100 pounds, than those fed on pea straw.

Since Lot III was fed pea straw and alfalfa as a roughage, and Lot II alfalfa hay alone, those two lots afford a further comparison of the roughages under consideration. Lots II and III required 583.05 pounds and 588.81 pounds of grain mixture per 100 pounds of gain, respectively. The grain expenditures per unit gain are so close that the effects of roughages in the two lots upon gain may be assumed identical. This suggests that 570.44 pounds of alfalfa may be replaced by 386.92 pounds of pea straw plus 287.01 pounds of alfalfa, or that 283.40 pounds of alfalfa hay may be replaced by 386.90 pounds of pea straw. This is approximately the same relationship as obtained above from a comparison of Lots I and II; that is, one pound of alfalfa hay fed in this way was equivalent to 1.3 pounds of pea straw.

MARKETING

Shrink

At the end of the experiment, the morning of February 29, the steers were fed as usual, excepting those in Lot IV, which were not given any silage. During the afternoon of the same day the cattle were driven to the local stock yards, a distance of about one and a half miles, and were loaded at seven o'clock that evening. They were unloaded and weighed at the Union Stock Yards, Spokane, Washington, at eight o'clock the next morning. It was not feasible to get lot weights on the cattle at this time. However, the loss in weight during shipping, based on average of all steers, will be of interest to cattle feeders.

TABLE VIII
Average of Weight, Shrink and Fill, for Twenty-four Steers

	Pounds
Weight at Feed Lot, February 29	1,200.7
Weight off Cars at Spokane, March 1	1,129.2
Shrink—Pullman to Spokane	71.5
Weight at Time of Sale	1,203.7
Weight of Fill in Stock Yards, Two Days	74.5

The second line gives the average weight based on all 24 steers at the time they were unloaded at the Union Stock Yards, Spokane, Washington. The third line represents the difference between the final weight of the cattle at the Experimental Feeding Shed and the average weight at the Stock Yards. (See Table VII).

Table IX gives a financial statement of the experiment from the time the cattle were purchased until they were sold. Attention is called to the fact that cost of marketing is high because the cattle were kept on exhibition during the Northwest Live Stock Conference. Further, no credit is given for the 100 tons of manure produced as a by-product of this feed-

TABLE IX
Financial Statement

Per Head Average	Lot I— Pea Straw.....	Lot III— Alfalfa Hay.....	Lot III— Pea Straw Alfalfa Hay..	Lot IV— Pea Straw Corn Silage...
Cost at Stock Yards @ \$10 cwt.	\$102.22	\$102.22	\$102.22	\$102.22
Other Expenses up to beginning of Exp., Morn. Nov. 25	5.96	6.17	6.06	6.16
*Cost of Feed During Experiment	60.53	66.26	63.45	62.84
†Cost of Marketing	6.33	6.33	6.33	6.33
Total Cost	\$175.04	\$180.98	\$178.06	\$177.55
‡Sale Price	154.27	161.21	159.03	155.13
Loss	\$20.77	\$19.77	\$19.03	\$22.42

*Barley, steam rolled, \$63 per ton; Pea Straw, \$15 per ton, baled; Alfalfa, \$28 per ton, baled; Corn Silage, \$10 per ton; C. S. M., \$80 per ton.

†The cattle were on exhibit at the yards from 8:00 a. m., March 1, to 10:00 a. m., March 3, at which time they were weighed up and sold.

‡Lots I, III and IV sold for \$13.00 per cwt., while Lot II sold for \$13.25.

ing operation, which is of value. And again the price paid for hay and pea straw includes the cost of baling and delivery to the Experiment Station Farm, which charge would have been reduced by \$5 to \$8 per ton if the feeds had been fed from the stack on the farm where they were produced.

Dressing Percentage

Each of the four lots of steers was purchased by a different packer. All the dressing percentages were based upon cold weight of carcasses. Where the cold weight was not actually obtained, 3 per cent* of the warm weight was deducted to obtain the cold weight.

Lot I, the pea straw lot, dressed 58.16%, the highest of all four lots. The other three lots showed very little difference, dressing about 57.50 per cent. This difference may be partly explained by the difference in fill. It was quite apparent from the appearance of the cattle on foot that the lots not accustomed to alfalfa hay did not fill as much as those which had been receiving it during the experiment.

TABLE X
Dressing Percentage

	Lot I	Lot II	Lot III	Lot IV
Kind of Feed	Grain Pea Straw	Grain Alfalfa Hay	Grain Alfalfa Hay Pea Straw	Grain Pea Straw Corn Silage
Purchased by	J. Lewis Co. Packers	Armour Co	Carsten Packing Co.	A. L. Brown
Weight per Lot	7,120	7,300	7,340	7,160
Av. Wt. per Head, lbs.	1,186.7	1,211.7	1,223.3	1,193.3
Carcass Warm Weight	4,269	4,318*	4,371	4,239
% Shrink on Cooling	3	2 ½	3	3
Cold Wt., lbs.	4,141	4,210	4,240	4,112
Dressing % Based on Cold Wt.	58.16	57.68	57.70	57.43

*Calculated from % supplied by Armour & Co.

SUMMARY

(1) The protein of pea straw is 58.4 per cent digestible, while the organic matter is 61.5 per cent digestible.

(2) Pea straw contains 3.53 pounds of digestible protein per 100 pounds and 53.36 pounds total digestible nutrients.

(3) Pea straw in this particular trial successfully replaced alfalfa in rations of fattening steers.

(4) One and one-third pounds of good pea straw was equivalent to one pound of alfalfa hay for fattening cattle.

(5) When pea straw and silage were fed, one pound of pea straw had the feeding value of two and one-half pounds of corn silage.

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STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIRECTOR'S OFFICE

Thirtieth Annual Report

For the Year Ending June 30, 1920

BULLETIN No. 158
NOVEMBER, 1920

**All Bulletins of this Station are sent free to citizens of the State on
application to the Director**

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Edward C. Johnson, M. A.	Director
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E. F. Gaines, M. S.*	Cerealists
O. E. Barbee, B. S.	Assistant in Farm Crops
F. J. Stevenson**	Assistant in Farm Crops
George Severance, B. S.	Farm Management
E. R. Johnson, B. S.	Research Fellow in Farm Management
Joseph Passonneau, B. A.**	Farm Markets
Chas. D. Bohannon, A. B.	Assistant in Farm Markets
O. M. Morris, M. S.	Horticulture
Roy Larsen, B. S.***	Assistant Horticulturist
O. L. Waller, Ph. M.	Irrigation Engineer
F. D. Heald, Ph. D.	Plant Pathology
B. F. Dana, M. S.	Assistant in Plant Pathology
R. V. Mitchell, B. S.	Poultry
F. J. Sievers, B. S.	Soils
Henry Holtz, M. S.	Assistant in Soils
J. W. Kalkus, D. V. S.	Veterinary Science

M. A. McCall, M. S.** Superintendent Lind Branch Station
 C. E. Hill, B. S.** In charge Waterville Branch Station
 R. P. Bean, B. S.** Superintendent Washington Irrigation Station

*On leave.

**In co-operation with the United States Department of Agriculture.

***In co-operation with Chelan County.

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Pullman, Washington.
November 1, 1920.

Honorable Louis F. Hart, Governor,
Olympia, Wash.

Sir:—

Pursuant to the act of Congress, March 2, 1887, relating to the establishment of agricultural experiment stations, I have the honor to transmit herewith a report of the activities of the Washington Agricultural Experiment Station from July 1, 1919, to June 30, 1920.

Suggestions as to some of the needs of the Experiment Station and a financial statement also are included.

Very respectfully,

EDWARD C. JOHNSON,
Director.

DIRECTOR'S STATEMENT

Introduction

In the year's activities of the Experiment Station, marked progress has been made and much valuable information accumulated. While in some instances, it was necessary temporarily to discontinue work on certain projects because of lack of funds, greater concentration was made upon others and results valuable to the agriculture of the state achieved.

The feeding and nutrition trials with home-grown feeds should prove of real value to every farm where live stock is handled and feeds grown, and the results already secured in a study of calf rations and in the experimental work on the effect of exercise upon the breeding ability of dairy bulls should be of help to every dairyman.

The continuation of the work that has been under way for a number of years in the Divisions of Crops and Soils in the production of smut resistant varieties of wheat, in investigating methods of maintaining the humus and nitrogen supply of the soil, and in the effect of tillage upon moisture and nitrogen content, will be of value to every farm where these crops are grown and where attention to soil fertility and soil moisture is needed.

The work done by the Division of Horticulture, especially in its cover crop and soil management investigations, is of interest to every orchardist of the state.

The studies of the Division of Plant Pathology in the methods of control of smuts, the Rhizoctonia disease and diseases of fruits, together with the work of the Division of Entomology in the study of the wire worm, the codling moth and insect sprays are of immediate concern to the producer both of field crops and orchard products.

The goitre investigations recently completed by the Division of Veterinary Science have been of great service to the practical stockmen in the goitre-infected areas, and the study of Red Water in cattle and the Orchard Horse disease now under way should result in much helpful information.

Similar mention might be made of the work done in the Divisions of Chemistry, Bacteriology, Botany and Farm Man-

agement and the Office of Markets. A careful perusal of the reports by Divisions in the following pages and of the publications issued from time to time from the Experiment Station will bring to each one a more complete understanding of the work of the Experiment Station and Branch Stations and its relation to the agriculture of the state.

Investigations in Co-operation with the U. S. Department of Agriculture

The investigations in cereal and forage crop production conducted in co-operation with the Office of Cereal Investigations and the Office of Forage Crop Investigations of the U. S. Department of Agriculture were continued as heretofore at the Adams Branch Station at Lind and the Branch Station at Waterville and increased emphasis was placed upon the co-operative work in breeding wheats for smut resistance at Pullman.

Co-operation with the Bureau of Entomology in wire worm investigations, commenced a year ago, was continued, the work being done primarily in the Adams County area, with headquarters at Lind and Ritzville.

Co-operation with the Office of Horticultural Investigations of the U. S. Department of Agriculture, relative to seed potato production, was continued, the work being done at Pullman, at the Irrigation Station at Prosser and in co-operation with farmers.

Co-operation with the Office of Farm Management of the U. S. Department of Agriculture and with the University of Idaho in investigations in the cost of producing wheat and in the organization of wheat farms was commenced. Co-operative work with the Office of Farm Management in a study of dairy-farm organization and the cost of producing dairy products was continued until January, when the representative of the Office of Farm Management resigned and was not replaced. This work is now conducted independently by this Experiment Station. Co-operation with the Office of Farm Management in the very important studies of farm organization and cost of production is, however, very desirable and it is hoped that it may be resumed in the not distant future.

The work of the Office of Farm Markets, which is very closely associated with the Experiment Station, was continued with the helpful and harmonious co-operation of the Office of Markets of the U. S. Department of Agriculture.

Changes in Staff

There were few changes in the staff during the year. The following resignations and appointments became effective:

Resignations—

- J. P. Fairbank, Head, Dept. of Agr. Engineering. June, 1920.
- Charles H. Hunt, Assistant Chemist. June, 1920.
- Harry H. Hill, Asst. in Dairy Manufactures. March, 1920.
- Milton Brandt, Asst. in Bacteriology. May, 1920.
- H. N. Colman, Supt. Advanced Registry Testing. April, 1920.

Appointments—

- J. L. St. John, Asst. Chemist. September, 1919.
- Fred S. Martin, Acting Supt. Official Testing. April, 1920.
- Roy Larsen, Asst. Horticulturist. February, 1920.*
- E. R. Johnson, Research Fellow. June, 1920.

There was no new legislation affecting the Experiment Station during the year.

Needs of the Experiment Station

Some of the more important needs of the various Divisions of the Experiment Station are indicated in the divisional reports.

While the state appropriations for the experiment station for this biennium were larger than those of the last biennium, the appropriations of the Federal Government through the Adams and Hatch Acts have remained unchanged. As a result, the very great increases in costs in conducting work due to the higher prices of equipment and materials of all kinds and the increased cost of labor absorbed the increased appropriations.

There is a constant demand from the people of the state that investigations be made of many agricultural problems which

*Chelan County pays the entire salary of Mr. Larsen and furnishes a fund for the expenses incurred.

thus far it has been impossible to undertake with the means available. For instance, there is demand for a very careful investigation of the collar rot and winter injury of apple trees in large sections of the state. Questions in regard to orchard bi-products, that can not be answered because information is not available, constantly arise. , No comprehensive study has been made of the methods used by farmers in logged-off areas in gaining a foothold upon the land. There is little, if any, organized information in regard to the best methods of clearing logged-off land and the cost of such clearing.

Horse management problems have received little, if any, attention by this Experiment Station.

Practical methods of reclamation of alkali land through drainage, proper handling of water and careful soil management are still to be worked out. Emergency problems in insect and plant disease control arise from time to time. Questions as to the cost of production of farm products and the best methods of organization of farms of various types are largely unanswered. These are only a few of the many problems relating to agriculture constantly confronting the farmers of the state and it is highly desirable that information to help solve them be made available as rapidly as possible.

The effective work of the Office of Markets in its studies of methods of marketing of the various farm products and in its helpful relations to the co-operative marketing organizations that are rapidly forming should receive adequate financial support. Indeed, the agricultural conditions of the state are so varied, its problems so numerous and its people so interested in investigational work that will be helpful to agriculture, that any appropriations made by the state for increasing the staff of the experiment station and for increased maintenance in order that the work may be expanded and vigorously prosecuted are a distinct investment.

Buildings and Land

Due to a destructive tornado which passed over the College farm in July, 1920, the sheep barn, horse barn, bull barn, egg-laying contest building and part of the poultry plant, as well

as a small orchard, were destroyed. Inasmuch as the farm buildings are used both for the college work and experiment station work, the experiment station will be hampered considerably until appropriate new buildings are constructed.

A building program has been proposed for the erection of a dairy barn, beef cattle barn, sheep barn, poultry plant and hog barn, as well as the remodeling of the old beef cattle and dairy barn for a horse barn, machine shed and seed rooms. Care should be taken so that the buildings constructed will be adapted not only for the use of the college departments but for such experimental and investigational work as the corresponding divisions of the experiment station will be expected to conduct at least for the next decade.

Additional greenhouse space is essential for the Divisions of Plant Pathology, Bacteriology, Chemistry and Soils in order that much investigational work that can not be conducted in the field may be done under controlled conditions in the greenhouses.

At the Irrigation Branch Station, a building program was commenced during the year and two laborers' cottages and a large machine shed constructed. A large basement at one end of the machine shed serves for the time being as a horse barn. A well was driven and a water system installed, and several hundred trees were planted. There is real need that the building program be continued the coming year by the construction of an additional farm cottage, a laboratory and seed storage building, feeding sheds, silos, pens and yards and a cottage for the superintendent. Much additional farm equipment, such as grain binder, corn harvester, silage cutter, small grain thresher, platform scales, etc., will be needed.

The Adams Branch Station at Lind is comparatively well equipped and no additions to the buildings are at present contemplated.

The Waterville Branch Station is conducted in large measure on rented land and unless this land were to be donated to the station or purchased for the station, it would not be advisable to erect any buildings. Except for a small office and laboratory building on the small farm and the old barn

and dilapidated house on the larger farm, there are no buildings on the station. The horses are kept in the barns of the Douglas County Fair Grounds immediately adjoining the small station farm.

Very little new equipment will be needed at either of the two dry land stations.

More land is needed at the State College for the growing of pure seeds for distribution to the farmers of the state. As improved varieties are secured by means of breeding and selection or through introduction from other states or countries, land should be available for growing them in such quantities that they may be sent to farmers desiring to use them.

The college farm, now consisting of about 560 acres, is used for all the experimental work and for the growing of some seed and some feed. There is always more demand for seed than can be supplied. Large quantities of feed also must be purchased each year for the stock on hand and with the increasing herds and flocks more feed will be needed. It should not be necessary to ship this in and to pay for freight as well as feed from current appropriations. With additional land on which to increase and grow seed for distribution, the land now devoted to this purpose would be available for necessary expansion of pastures and for feed production.

Additions to the Staff

Additions to the staff in many instances are highly desirable. In some cases, where additional instructors in the college also are needed, such additions can be made by the appointment of men for part time work in the college and part time in the station or full time in the college or station, thus making available for experiment station work some time now devoted to teaching by present members of the staff of the college and station. In some cases desirable additions may be made by the appointment of research assistants in the nature of graduate fellowships and scholarships. This practice not only will give much needed help in many experimental and research projects, at a minimum of expense, but also will give training to men much needed now and in the future in the experiment station and college work.

DIVISION OF ANIMAL HUSBANDRY**H. Hackedorn, in Charge****Pea Straw for Fattening Cattle.**

Investigations relative to the best methods of utilizing pea straw were continued. In digestion trials with steers, it was found that pea straw contains the following percentage of digestible materials: proteins, 3.53%; fat, .75%; crude fibre, 18.55%; and nitrogen free extract, 29.59%. The nutritive ratio of the feeds was found to be 1 to 14.1.

Four lots of six steers each were fed the same quantities of a 7 to 1 mixture of rolled barley and choice cottonseed meal. Lot I received pea straw; Lot II, alfalfa hay; Lot III, pea straw and alfalfa hay; and lot IV, pea straw and corn silage.

Comparisons of Lots I and II indicate that one pound of pea straw has the feeding value of three-fourths pound of alfalfa hay. Lots I and III compared show the same relationship, thus supporting the first comparison. Comparisons of Lots I and IV indicate that one pound of pea straw has the replacing value of 2.2 pounds of good corn silage. All lots consumed 15 pounds of grain mixture per head daily, and required from 560 to 595 pounds grain, in addition to the roughage, for each 100 pounds of body gain. Lot I received 1 part grain to 1.3 parts pea straw, while Lot II received grain and alfalfa hay in equal proportions.

Sunflower Silage for Sheep.

In analyses of sunflower silage taken from various depths of the silo, it was found to contain 22.1% dry matter; 1.72% crude protein; 1.76% crude fat; 6.42% crude fibre; 9.96% nitrogen free extract; and 2.16% ash. Digestion trials with sheep have shown that sunflower silages contain the following percentages of digestible nutrients; crude protein, 1.00%; fat, 1.45%; crude fibre, 2.50%; and nitrogen free extract, 5.67%.

Two lots of five lambs each, averaging 85 pounds per head, were fed barley, cull beans and pea straw. One lot received corn silage, the other sunflower silage.

The corn silage lot required 442 pounds grain, 187 pounds pea straw and 526 pounds corn silage, per 100 pounds body gain. The sunflower silage lot required 666 pounds grain, 310 pounds

pea straw and 811 pounds sunflower silage. The sunflower silage lot evidently had a larger grain requirement per 100 pounds body gain, but the small number of lambs per lot does not warrant definite conclusions.

Sunflower silage fed to a flock of breeding ewes for sixty days before lambing gave as good results as corn silage as far as the condition and the weight of the ewes were concerned.

Study of Comparative Value of Protein Supplements in Swine Rations.

A three to one mixture of rolled barley and wheat shorts was used as a basal grain mixture fed to pigs averaging 45 pounds at the beginning of the experiment and finishing at 225 to 250 pounds. Lot I received tankage, Lot II, linseed oil meal, Lot III cocoanut meal, and Lot IV fish meal.

The proportion of supplement to barley and shorts was decreased as the pigs increased in weight so as to widen the nutritive ratio. All the mixtures at each point of the experiment contained the same ratio of protein to carbohydrates. The ratio of grain mixture to supplement varied as follows: tankage lot, from 7 to 1 up to 16 to 1; linseed oil meal lot, 3:1 to 9:1; cocoanut meal lot, from 1:1 to 3 $\frac{1}{4}$:1, and the fish meal lot from 7:1 to 12:1.

The ration containing cocoanut meal was too bulky and the gains were least economical. The tankage lot required 403 pounds grain per 100 pounds body gain, the linseed oil meal lot 334 pounds, the cocoanut meal lot 440 pounds and the fish meal lot 339 pounds.

Work involving economical utilization of forage for pork production was planned: (1) to study the value of protein supplements for grain mixtures fed to hogs on legume forage, and (2) to determine the value of forage in terms of grain. It was satisfactorily demonstrated that a protein supplement is highly desirable in hog rations fed in connection with alfalfa forage. A protein supplement fed in grain rations in connection with pea forage did not effect any saving of grain per unit of gain. Pigs hogging off corn will make more economical gains if given a protein supplement.

In 44 days, an acre of alfalfa carrying 28 $\frac{5}{8}$ pigs effected the

saving of 877 pounds of grain as compared to full feeding in dry lot. An acre of pea forage carrying $3\frac{3}{4}$ head per acre for 60 days effected a saving of 679.5 pounds grain in contrast to dry lot feeding. (The peas yielded 24 bushels per acre). Fifteen 94-pound pigs hogged off an acre of corn in thirty days which would have yielded 36.7 bushels per acre. Without any additional grain fed, the hogs produced 487.5 pounds pork per acre.

The quantity of peas and corn not utilized indicated that the number of hogs per acre of forage could be profitably increased.

Needs of the Animal Husbandry Division.

One of the greatest needs in the investigational work is more comprehensive library facilities. Practically no reference books are available except the experiment station records and files of bulletins published by various experiment stations in this country. It will require a considerable library fund to secure the much needed publications.

A laboratory for conducting digestion trials with cattle, sheep, hogs and horses is needed. This would not require a large expenditure of money and would add materially to the efficiency of the experimental work.

A normal increase in the experimental work along nutrition lines will require a chemist to do routine analytical work.

Some experimental work on the problem of wintering the idle horse and also the growing of horses on the farms is important in this section and should be undertaken at the earliest opportunity.

DIVISION OF BACTERIOLOGY

T. J. Murray, in Charge

Legume Culture Work.

Inoculating material was prepared and furnished to the farmers of the state in quantity sufficient for 10,044 acres of legumes.

A Comparison of Different Inoculating Cultures:

A study of different types of inoculating culture was continued in different parts of the state. The college alfalfa culture was compared with commercial cultures at the Western Washington Experiment Station. At Wenatchee, college cultures of vetch, peas and alfalfa were compared with commercial cultures. In co-operation with the University of Idaho, the college bean culture was compared with the University of Idaho culture and several commercial cultures at Lewiston, Idaho. The results of this work have not yet been obtained.

Factors That Control the Infection of Legumes by Bacteria.

No work was done on this project this year, due to lack of available greenhouse space.

Bovine Tubercle Bacillus.

In the work on this project last year, it was found that when urea was substituted for glycerine in Magoon's synthetic Media, the tubercle bacillus ceased to grow. This year many of the common and rare sugars were substituted for the urea. Satisfactory results have not yet been obtained in getting a fat free tubercle bacillus.

The Effect of Straw on the Soil.

The laboratory work on this project has been practically completed. A bulletin covering the results has been prepared and will be published.

Miscellaneous Analysis.

Numerous analyses of water and of milk have been made for the people of the state.

Needs of the Division of Bacteriology.

More room for the experiment station laboratory is needed as well as greenhouse space where temperature, humidity and light can be adequately controlled. More time should also be available to the experiment station bacteriologist for research work than heretofore in order that some of the projects now under way may be given additional attention and in order

that there may be opportunity to co-operate more fully with other divisions in joint projects where bacteriological work is not only desirable but essential.

DIVISION OF BOTANY

F. L. Pickett, in Charge

The station botanist has oversight of the seed laboratory during the school year and immediate direction of the work of this laboratory during the summer vacation of the analyst. About 1500 germination tests and almost as many purity tests were made during the year.

Following the work of previous years, extensive data as to weed introduction and distribution have been gathered by correspondence and tabulated. In this connection about 700 inquiries by farmers have been cared for by identification of weeds or by suggestions as to eradication.

No funds were available this fiscal year for labor, materials or supplies for experimental work. The wild morning glory eradication investigations begun the previous year, therefore, were dormant during the year. It is hoped, however, that in the next biennium, funds may be available for experimental work dealing with possible methods of eradication or control.

Due to shortage of help and consequent increase of time needed for routine duties, it has been impossible to continue the work on the weed bulletin mentioned in the last report.

THE DIVISION OF CHEMISTRY

Geo. A. Olson, in Charge

Baking Qualities of Flour.

The investigations of the "Baking Qualities of Flour" conducted this year were divided into two groups, as follows:

- (a) The influence of variation in the quantity of inorganic salts, sugar and yeast on the baking quality of flours having different and equal gluten contents.

(b) A study of the pepsin digestion of various glutens.

In the use of salts, sugars and gluten in various combinations, it is found that the addition of sugar alone offers a greater volume production than is obtained with or without salt alone. It is known that salt tends to make the dough firmer. The addition of calcium hydrogen sulphate to the sugar salt combination produces a slight increase in volume when compared either with results of the sugar or the sugar and salt combination. When the gluten content of the flours have been made exactly the same and the salt and sugar included, there is some improvement in volume but the volume production remains in the same order as it was without the gluten.

In previous publications from this Division, it has been shown that the water soluble extracts exert the greatest influence in volume production. The sugar and calcium hydrogen sulphate added make further improvements in loaf volume. Just what combination of the various components of flour will make the largest loaves of excellent texture is yet to be learned. Measurements are being made and it is hoped that something definite will result.

In the proteolysis studies of the glutens, some very interesting information has been obtained. The present findings show that the glutens and the total flour proteins, including the glutens, have digestion values of very wide range.

Washington flour glutens appear to be more resistant to pepsin digestion than has been the case with glutens obtained from other sources.

At the present time it is impossible to state whether the differences noted above are due to climatic or varietal conditions. It is known, however, that the information obtained can be used to differentiate between the various qualities of the gluten. In case it should be found that the differences are varietal and inheritable, then it would follow that gluten quality could be controlled through breeding and selection.

From a commercial point of view, a rapid method of measuring the quality of glutens could be perfected and, if further

experimentation should support the present findings, it would be worth while to work out such a device.

Greenhouse space and the construction of a lysimeter is needed in order that the work on the function of sulphur as a plant food, a project already under way, and the studies of the relation of the composition of wheat to soil types may be continued.

STATE CHEMIST

The Chemist of the Washington Experiment Station, who is also State Chemist, has assisted both the State Department of Agriculture and the Department of Secretary of State by doing analytical work and giving expert testimony when requested in cases involving the laws administered by these Departments.

Insecticides and Fungicides.

A small number of insecticides and fungicides were submitted to this division for analysis. These samples were analyzed and reports given to the proper authorities.

Dairy Products.

Samples of milk, cream, butter and cheese were analyzed. Some of the samples were found to run below the standards.

Fertilizers.

Analyses of samples of fertilizers show a large number running below in one or more of the fertilizer ingredients guaranteed by the manufacturer. Perhaps wider publicity than is now given would aid in bringing the quality of the fertilizers up to the guaranteed values.

Foods.

The quality of the samples of food submitted was very good. Some vinegar samples analyzed were found to be below the state standards. Two brands of condensed milk manufactured by one company showed from analysis that they were sold in violation of the regulations of this state. A large number of analyses of sirup advertised on bills of fare by restaurant own-

ers as maple sirup, showed them to be corn, cane, or a combination of corn and cane sirups with or without artificial flavoring and coloring matter.

Feeding Stuffs.

In the early part of the year following the enforcement of the new feeding stuffs law of this state, samples were analyzed which did not measure up to the values guaranteed by the manufacturers. Since that time only a very small number of feeding stuffs have shown values which were not better than those guaranteed by the manufacturers. The improvement in the quality of the stock foods sold in this state, due to the requirements stipulated in the statutes and the rigid enforcement of them by the State Department of Agriculture is very marked.

Short Weight.

The State Chemist determined the moisture content of samples of flour which were found to be short weight by deputy sealers from the office of the Secretary of State. This assistance was of help in determining whether or not the flour was short weight due to loss of moisture or had been sold with a moisture content in excess of that permitted in the food regulations.

THE DIVISION OF DAIRY HUSBANDRY

E. G. Woodward, in Charge

Sunflower Silage vs. Corn Silage.

A feeding trial for the purpose of comparing sunflower silage with corn silage as feed for milk production was conducted with eight cows. These were fed for eighty days. Four cows were started with sunflower silage and four with corn silage. The feeds were reversed at the end of forty days.

Tabulation of Results of Feeding Sunflower Silage and Corn Silage
Totals for Groups

Ration	Cows	Silage lbs.	Hay lbs.	Grain lbs.	Milk lbs.	Gain or Loss, lbs.
Sunflower silage	8	8261	4240	3285	7610	—3
Corn silage	8	9152	4244	3029	7575	+ 123

The interpretation of results is somewhat difficult, due to the fact that cows receiving corn silage gained in weight while those on sunflower silage remained practically the same in weight. The cows receiving corn silage ate 891 pounds more than those receiving sunflowers. At the same time the corn silage group gained approximately 125 pounds more than the sunflower group.

On the other hand, the sunflower group ate 256 pounds more grain than the group receiving corn silage. If, in interpreting the results, it is assumed that twenty pounds of silage is equivalent to one pound of grain in weight, it would mean that the cows on corn silage had gained during the experiment an equivalent of approximately 2500 pounds of silage, whereas they had actually consumed 891 pounds more silage than the sunflower group. This would leave a difference of approximately 1600 pounds in favor of the corn silage group.

If it is further assumed that the grain is five times as valuable as corn silage, the 256 pounds which the sunflower group ate in excess of the corn silage group would be equivalent to 1280 pounds of silage. This added to the 1600 pounds for the corn silage group would make a total difference between the groups of 2880 pounds of silage.

Based on the assumption that the grain is five times as valuable as the silage and the hay three times as valuable, this 2880 pounds is equivalent to practically eight per cent of the entire ration. In other words, it might be said that the sunflower silage was approximately 92 per cent as valuable as the corn silage in this trial.

This report must, however, be taken merely as a preliminary finding, as it is based upon one trial for a single year.

Another point of interest brought out by this trial is the fact that sunflower silage was considerably less palatable than the corn silage. A number of cows did not relish the sunflower silage to begin with and in fact seemed to be consuming it almost to the limit of their appetite, whereas undoubtedly they would have eaten a considerably greater quantity of corn silage.

The corn silage used in this trial was of especially good quality, being quite rich in grain. The sunflower silage would probably be considered as of medium quality. It was quite dark in appearance, although seemingly it kept well.

A Study of Calf Rations.

In the study of the value of different calf rations, three prepared calf meals, skim milk and whole milk were fed to young calves. The change from whole milk to calf meal or to skim milk was made gradually, beginning at the age of fourteen days. Most of the calves were on the new ration by the time they were twenty-five days old.

The calves receiving the skim milk and the milk substitutes made satisfactory growth. However, they did not look as smooth in some cases as those fed skim milk or whole milk.

The Effect of Exercise and Feed Upon the Vitality and Breeding Ability of Bulls.

The Ayrshire, Jersey and Holstein herd bulls owned by the college were used in this investigation. Exercise was given on a tread mill at the rate of two and a half miles an hour for thirty minutes a day. A sample of semen was taken from the cow after service and the vitality of the spermatozoa as indicated by their motility was determined by means of the microscope.

The results may be summarized as follows: In the case of a slow bull, exercise greatly diminished the time required for service. A greater percentage of the spermatozoa were motile, when the bulls received exercise, than when they were kept in box stalls without exercise. When the bulls were exercised, 60% to 100% of the spermatozoa were motile, without exercise 5% to 45% were motile.

When the bulls were exercised, the spermatozoa were more vigorous, as evidenced by the fact that they were motile for a longer period of time than was the case where the bulls were kept in box stalls without exercise. With exercise some motion of the spermatozoa was noticeable for 22 to 39 hours; without exercise motion ceased in from 3 to 24 hours.

Needs of the Division of Dairy Husbandry.

More help is needed on the staff of the Dairy Division, both in the college and station. Only a very limited time on the part of the head of the Division is now available for investigational work and the details of such work must be handled by advanced students. This should be remedied as soon as there are funds for additions to the staff.

Official Dairy Testing Work.

The number of breeders doing official testing work, July 1, 1920, is as follows: Ayrshire, 4; Guernsey, 20; Holstein, 54; Jersey, 34; or a total of 112.

The number of cows on test between the dates given is as follows: Ayrshire, 38; Guernsey, 52; Holstein, 486; Jersey, 297, or a total of 837 cows.

The kinds of tests made from July 1, 1919, to July 1, 1920, are as follows: Two day tests, 3869; seven day tests, 323; thirty day tests, 28; retests, 84, or a total of 4304.

The first six months of the year 1920 shows an increase of 85 per cent over the corresponding period of the previous year, the largest increase being in the semi-official work where the increase was 86 per cent. The official work showed an increase of 51 per cent.

DIVISION OF ENTOMOLOGY AND ZOOLOGY

A. L. Melander in Charge

Codling Moth.

Practical orchard spraying was begun early in the summer at Cashmere, Opportunity and Moran to determine experimentally the relative value of various treatments. The experiments were conducted partly in connection with the Extension Service and partly articulating with those of the U. S. Bureau of Entomology at Yakima. The following results were obtained:

(a) The coefficient method of rating has shown a slight advantage in favor of the clipper nozzle over the spray-gun

at the calyx application, notwithstanding opinions to the contrary, based on the final percentage of worm free fruit.

(b) Powdered arsenate of lead gave slightly better results than calcium or magnesium arsenates, and this year proved somewhat better than the paste form. Calcium arsenate showed no scorching even where the lime or lime sulphur was omitted.

(c) There was not enough improvement when using strong sprays to warrant recommending a spray much stronger than one pound of powdered lead arsenate to 75 gallons.

(d) During the process of spraying, the addition of four to six bars of laundry soap helped materially in increasing the covering ability of the spray. However, the added spreader did not increase returns in worm free fruit.

(e) Late sprayings proved very necessary in the orchards under treatment, which were selected because of particularly heavy infestation. The calyx spraying alone, though given with the utmost care and thoroughness, would not have sufficed. Of the three places, the orchard at Cashmere has the least loss, due undoubtedly to the careful thinning for wormy fruit during the time of the first brood. It is quite clear that such thinning is more valuable than late spraying in preventing the crop from becoming wormy.

Winter Kill of San Jose Scale.

The project on the varying susceptibility of the San Jose scale to insecticides was changed this year to a study of winter mortality due to the almost unprecedented cold weather of October and December. It was found that throughout the scale district the mortality was in general greater than that usually following spraying. In some sheltered places the winter-kill amounted to 75 per cent but elsewhere the mortality was excessive, becoming practically a complete extermination in some districts. Resistance to sprays, as determined by districts during the investigation of previous years, was not correlated with survival over the past winter, the winter kill

being entirely a matter of degree of coldness. A paper dealing with the details of the findings will appear shortly in the Journal of Economic Entomology.

Cranberry Insects.

The study of the insects, particularly the fireworm, affecting cranberries in southwestern Washington conducted the past two seasons in cooperation with the Bureau of Entomology of the U. S. Department of Agriculture was brought to a close in September. The results of the investigation will be published by the Bureau.

Wireworms Affecting Wheat.

During the season of 1919 and again during 1920, a cooperative study of the soil insects of wheat has been conducted at Lind and Ritzville in collaboration with the Bureau of Entomology of the U. S. Department of Agriculture. Various methods of treatment are being practiced in an effort to discover some control that will be practical under the conditions of the extensive farming of this district.

The Borboridae of North America.

A monographic review of the species of this family of flies has been completed and is ready for publication.

Spray Poisoning of Bees.

In connection with the Extension Service and the Division of Apiculture, a survey of the extent of damage to bees from poison sprays has been carried on. A study of the little-known causes and prevention of this trouble will be made.

The Leaf Roller.

The most startling orchard pest of the year has been the leaf roller of the Spokane district. Preliminary work has been carried on by the entomologists with a view to more extensive investigation and an educational campaign the coming spring.

DIVISION OF FARM CROPS**E. G. Schafer in Charge****Varietal and Crop Adaptation.**

The results of recently compiled data show that certain varieties of wheat, including Forty Fold, Red Russian and others, which have been grown quite extensively, are of inferior value and for the most part should be eliminated. If the varieties grown in the state were restricted to those best adapted, an increase in production could be expected. Hybrid 128 and Turkey Red are among those which should be used for fall seeding. Bluestem, Early Baart and Marquis should be used for spring seeding, each variety being used in the locality to which it is best adapted.

The data obtained for oats indicate that Abundance has been the best yielding variety grown at the Experiment Station.

New varieties of field crops are being introduced from various sources each year and compared with the standard varieties of the state in order to determine their relative worth and protect the producers against untried introductions.

Cultural Practices.

The results of the various cultural experiments, which have been conducted on Field VI for a period of twenty years recently have been compiled and prepared for publication. These investigations include the manner of applying manure, summer fallow methods, wheat in rotation, fall and spring plowing for spring wheat, and depth of spring plowing for spring wheat.

The Production of Superior Varieties.

More than 3000 pure line selections and hybrids were grown experimentally during the year in search of more hardy and productive varieties of wheat. A large number of selections have been produced which show promise of superior quality, high yield and other desirable characteristics and are more resistant to smut than the wheats now grown commercially.

Similar investigations are being conducted with oats and barley.

The Study of Plant Breeding Laws.

Several crosses between widely different types of grain have been made in order to determine the underlying laws of their inheritance. Such characteristics as size of grain, sterility, color of straw, chaff and kernels, hardness of grain, winter hardiness and smut resistance have been observed and analyzed in the second and later generations.

Forage Crops and Practices.

A forage nursery has been established in which 341 varieties and selections of alfalfa, clover, peas, beans, sunflowers and grasses are being grown to determine comparative values. Special attention is given to the work of establishing forage crops in order that such crops may be of benefit in promoting livestock production and maintaining soil fertility.

Crop Rotations.

The permanent crop rotation experiment which started recently is well established. Yields of the various crops of the rotation were obtained from the various plots in 1919 and the cropping system is being conducted according to outline.

Distribution of Seed.

Pure seed of varieties that have proved superior have been distributed to the different parts of the state to which they seemed adapted. A total of 94,613 pounds of seed were distributed in 225 shipments to 25 different counties.

The work of supplying pure culture for alfalfa, clover, field peas, etc., has been continued and conducted cooperatively with the Division of Bacteriology. Sufficient bacterial culture to inoculate 10,044 acres was sent to 1,188 parties and went into every county in the state.

DIVISION OF FARM MANAGEMENT

George Severance in Charge

The work of the Division of Farm Management for the past year has been centered upon two projects, namely: "The Cost

of Milk Production and Dairy Farm Organization" and "Studies on the Cost of Wheat Production and Grain Farm Organization in the Palouse." Work on the first project was begun in cooperation with the Office of Farm Management, U. S. Department of Agriculture, but since the resignation of its representative in January, this Division has been conducting the investigations alone. The work of the past year has consisted of accumulating detailed business records including labor distribution from a number of selected farmers. When complete records for one year have been secured they will be tabulated.

Work on the second project is being carried on in cooperation with the Office of Farm Management of the U. S. Department of Agriculture and the University of Idaho. Detailed farm survey data for the year 1919, including labor distribution on all crops and on livestock, have been secured from 250 farms in the vicinity of Pullman, Washington, and Moscow, Idaho, and the data are now being tabulated by the Office of Farm Management.

THE DIVISION OF HORTICULTURE

O. M. Morris in Charge

Six projects were given attention during the year. Other projects have been approved and some work done on them but they are dormant at the present time.

Mendel's Law in Blackberry and Raspberry Hybrids.

Progress has been made in the work on this project. Special characters must be used for the basis of features or character segregation. The loganberry and dewberry used in one feature line of work seem to be practically intersterile and very few crosses were successful in producing seed for continuance of the work. The raspberry and loganberry crosses used for another feature study were inter-sterile and produced no viable seed, thus practically eliminating this cross from the work. Crosses between the blackcap raspberry and the red raspberry seem to be easily secured and a satisfactory num-

ber of seeds have been obtained for the tests of inheritance of vegetative methods of reproduction, the characteristics selected for study in this cross. It seems clear now, however, that the cross between blackberries and raspberries is too violent to permit of satisfactory seed formation. It is not planned, therefore, to continue work in this direction.

Apple Rosette.

Repeated careful surveys have failed to find evidence that apple rosette is present in any orchards other than those on alkali soils. It seems clearly demonstrated that the use of legume cover crops in the orchards causes the trees to recover from this trouble and resume normal growth. These cover crops reduce the evaporation from the soil's surface and tend to reduce the quantity of alkali in the surface soil.

Chemical analyses of more samples of badly rosetted twigs and their foliage and the normal twigs and their foliage have been made. The data secured show that the ash and alkali content of the rosetted material is much higher than in the normal material.

All of the work may be summarized as indicating that the accumulation of alkaline salts in the plant body is at least a contributing factor to the development of this abnormal formation.

Orchard Cover Crops.

Investigations in orchard cover crops constitute an important work of the Division. The work during the year made clear that hairy vetch is one of the best leguminous cover crops to use when first establishing the cover crop system. This plant shows an unusual ability to produce a large quantity of vegetation in one season. This decomposes rapidly and improves the physical condition of the soil. If left to decay on the surface, the soil condition is improved and the result in general soil and orchard improvement is marked as compared with plots in which the material is plowed under. When the vetch has been used for two or three years the orchard can be planted to alfalfa. If an abundant water supply

is available when alfalfa is planted, there will not be a severe contest between the orchard and the crop, for plant food materials, and very little, if any, noticeable check in the growth of the tree or the development of the crop.

It has been established that permitting the alfalfa to grow uncut through the season and fall on the ground to be worked into the surface soil in the spring by disking and similar processes, is more beneficial to the orchard than permitting the material to be cut and used as hay or to be cut and permitted to fall upon the ground to decay. It is possible to irrigate the orchard satisfactorily, even though the ground is covered with a heavy growth of alfalfa. Deeper and more permanent ditches are required, but the improvement in the orchard is worth more than the extra expense.

The cooperative fertilizer plots established in orchards in the Wenatchee district in 1919, gave no indication of beneficial results from any plots except those that were fertilized with nitrogen bearing fertilizers. This indicates that in those orchards the nitrogen in the soil is a limiting factor in tree growth and crop production and that so far as these orchards are typical of the district, the same result might be expected in other orchards.

Renovation of Prune Orchards.

The work on this project has again emphasized the importance of nitrogen as the limiting factor in soil fertility in the prune orchards of Clarke county.

The investigation brought together abundant evidence to show that heavy pruning of young trees is not necessary to their best development; and that old, weak, and declining trees often may be stimulated into the production of new and vigorous wood by heavy pruning after the soil is improved in physical condition and fertility.

Fruit Storage.

Trials made in storing apples grown in the summer of 1919 gave results which indicated that the fruit grown in the warm valleys of the state, if properly picked and handled, will keep

in storage approximately as well as that grown in the cooler areas. The difference in the keeping quality of fruit from the different localities seems to be due more to the state of ripeness attained by the fruit before harvest and the storage temperatures to which it is subjected after harvest than to any temperature to which it has been subjected while in the process of growth. The fruits used had not been subjected to temperatures of either extreme that were abnormal or would tend to prevent perfect development.

Seed Potato Production.

The work on this project indicates that the appearance of seed material at the time of the planting cannot be taken as conclusive evidence of what the material may be expected to produce in the crop to be grown. The value of seed potatoes is greatly modified by the storage conditions through which they pass and only best storage conditions should be used for seed material.

It is clearly established that in any one variety there may be developed strains with widely different production capacity. It is very important that the potato growers be able to secure seed material from the best producing strains.

Investigations Needed.

There are many other problems in this state affecting the production of horticultural crops which should be given serious attention.

One of these is grape growing. This crop does well in some sections of the state but the limitations of areas adaptable to this crop have not been well defined and lack of knowledge of this subject has caused very serious loss to the growers in several sections.

Work should be done in search for a hardy apple root stock which could be used as a foundation for apple trees to prevent the heavy annual loss as a result of winter injury to the root system and crown of the apple tree.

The biennial fruiting habit of several of our best varieties of apples is a serious problem involving methods of pruning,

thinning the fruit and systems of culture. The losses in fruit crop resulting from this habit of the trees is serious and should be given immediate attention.

Nut crop production is in need of investigation to determine the limits of the districts adaptable to commercial nut culture. Information is needed on variety adaptation to districts and on the point of self sterility and inter-sterility of varieties.

There is need of investigational work in methods of handling stone fruits, especially peaches, with the view of delaying the blossoming period in the spring.

Methods of management of cranberry bogs is also a subject of considerable importance. The cranberries in the northwest are produced under methods entirely different from those in the older cranberry sections and these systems, while having their advantages, also seem to have some very distinct disadvantages.

Vegetable seed production in the United States has become a matter of very considerable importance since the World War and the climate and soil of Washington have given promise of conditions favorable to the development of that industry. Careful investigation of methods and practices involved are seriously needed.

DIVISION OF PLANT PATHOLOGY

F. D. Heald in Charge

Wheat Smut.

The study of the relation of spore load of individual grains to the per cent of smut in the crop was continued. Samples of spring wheat showing different varieties and varying quantities of smut were obtained direct from the farms or warehouses. Spore counts showed 0 to 12,000 per grain for the different samples. The maximum per cent of smut was 5.49, while a considerable number of plantings remained entirely free. The results show much less smut than would have been predicted on the basis of tests from artificial infections for either spring or fall plantings. Marquis samples carried as high as 542 spores per grain but only a single sample produced smut

(1 per cent) in the field. Jenkins' Club and Hybrid 143 showed much more need of seed treatment than any of the other varieties tested.

This year has completed the third and final tests of 116 varieties of winter wheat for comparative resistance to smut. None were smut free but Turkey strains continued to show the least smut. The continuation of the testing of 86 varieties of spring wheat was carried out in cooperation with the Division of Farm Crops. For both winter and spring wheats, it may be noted that different strains of the same variety from different regions have shown wide variation in the quantity of smut in the crop.

Weekly plantings of heavily smutted seed from August 1 to November 21 showed the maximum smut (74.55 per cent) on October 3. Weekly plantings of clean treated seed on summer fallow for the same period showed no smut until the plantings of September 12 (4.5 per cent) with a maximum of 20.64 per cent on September 26. Five weekly plantings from October 24 to November 21 were entirely smut free.

In the tests of different seed treatments for the prevention of smut from naturally infected summer fallow, varying results were obtained. The 1-1 bluestone and the 1-1-1 bluestone and salt formulae gave a clean crop. This was not true for the less concentrated solutions but formaldehyde performed better than usual and also produced a smut-free crop.

Treatment of seed with formaldehyde does not increase susceptibility to smut if seed is subsequently smutted. The seed treatment work carried out by the Extension Pathologist has shown two important results. Seed injury with a given standard fungicide varies with the seed lot, which serves to emphasize the need of preliminary tests of germination before extensive seedings are undertaken. Formaldehyde injury can be greatly reduced by the lime-water bath following treatment, using the same strength as for protection from injury in the case of bluestone treatments.

The Plant Disease Survey.

The Plant Disease Survey conducted in cooperation with the

Plant Disease Survey Office of the U. S. Department of Agriculture has shown a number of troubles new to Washington and the recurrence of several diseases that had not been prevalent for a number of years. The following new troubles may be mentioned:

Bastard toad flax (*Comandra* sp.) parasitic on the roots of apple trees; moldy core of Stayman Winesaps; *Fusarium* root rot of corn; *Rhizoctonia* disease of the Dutch Iris; an internal necrosis of head lettuce which developed into a bacterial rot during shipment to eastern markets; potato streak and the skin spot (*Oospora pustulans*); *Botrytis* rot of strawberries.

Apple scab has been severe in Eastern Washington for the first time since 1915. The California blight of cherries, which had not been troublesome since 1915, was again severe in the Clarkston section; the *Sclerotinia* wilt of sunflowers (*Sclerotinia perplexa*) has been very prevalent in the Coast Country; potato mosaic and general degeneration of seed stock have been more in evidence than during the past few years.

Special work has been done on two of the new troubles: skin spot of the potato and moldy core of Stayman Winesap apples. The skin spot has been studied in the laboratory and field tests are in progress. The work on Moldy Core of Stayman Winesaps has shown that a considerable number of different fungi may be found in the core cavity but that only two of the forms, *Penicillium* and *Alternaria* species, are capable of causing a rot which advances outward into the pulp. The presence of mold in the core of a Stayman Winesap is no sure indicator of its keeping qualities.

Needs of the Division of Plant Pathology.

Numerous requests for investigational work that cannot be undertaken by reason of the limited time of the staff and the limited means available come to the Division each year. Especially urgent requests for a careful investigation of the collar rot in fruit trees have come this year as this disease is causing great injury in irrigated orchards of this state. It is hoped that during the coming biennium both additional help and funds will be available so that this problem may be studied.

DIVISION OF SOILS**F. J. Sievers in Charge****Soil Fertility Work in Western Washington.**

The work with fertilizer plots was continued in several counties. Results indicate conclusively that most acid soils are deficient in phosphorus, and that an application of lime alone generally gives poor results unless it is supplemented with a phosphate fertilizer. Indications are that much of the difficulty experienced in the growing of clover is due more largely to the deficiency in phosphorus than to the acidity of the soil.

Crop Rotation Work.

The rapid exhaustion of the organic matter and nitrogen in the soils of the Palouse, as a result of a summer fallow system calls for some provision whereby the organic matter and nitrogen may be maintained. Forty-eight plots on the rotation field on the College Farm are used to determine which legume can be fitted into a system of rotation most satisfactorily. The general plan is to substitute a legume for summer fallow. Legumes showing considerable promise are: alfalfa, sweet clover, red clover, mammoth clover, peas and vetch. A satisfactory nurse crop for these legumes is a matter of great importance. Barley, oats, wheat and peas were used as nurse crops with alfalfa, sweet clover, medium red clover and mammoth clover. On the basis of one hundred per cent stand for summer fallow, the following results were obtained:

Nurse Crop	Alfalfa	Sweet	Medium Red	Mammoth Red
	% Stand	Clover % Stand	Clover % Stand	Clover % Stand
Peas	80	70	30	20
Barley	40	40	10	0
Oats	30	30	0	0
Wheat	20	20	0	0

The climatic conditions during this season were decidedly unfavorable for the establishment of any of these legume crops. Nevertheless, the data indicate that peas can be used to good advantage as a nurse crop for alfalfa and sweet clover.

Tillage.

The results from tillage work at both Pullman and Lind were consistent with results reported last year. The amount of stooling of wheat was found to be directly affected by and proportional to the nitrate content of the soil at seeding time. The number of spikes of wheat produced per acre, within reasonable limits, is independent of the rate of seeding, but directly dependent on the nitrate content of the soil at seeding time.

Orchard Soil Investigations.

The results obtained from several soil examinations established the fact that in all irrigated tracts there must be sufficient water available not only to supply the quantity necessary for bearing trees but also to provide for the growing of a legume between the trees. The virgin nitrogen supply in irrigated orchard tracts is exceedingly low and successful yields demand that this supply not only be maintained but actually increased.

Control Work in Jars.

Work is under way to determine the minimum, maximum and optimum moisture supply in soils for nitrification. That there is a point in the moisture supply in the soil where the nitrification process is definitely affected is very evident and since summer fallowing is practiced largely to promote nitrification the results of this investigation have an important bearing on this practice. The effect of variations in the nitrogen content of crop residues on their rate of decomposition when returned to the soil is being determined. The results of this work should have a definite value in controlling the available nitrogen supply in the soil and thus eliminate in part, at least, the unsatisfactory yields caused by poor stands and burning.

Miscellaneous Work—Soils.

About 450 soil samples sent in by farmers were tested and reports made; 25 samples of marl and limestone were analyzed and 92 samples of soil tested for alkali. Several soil surveys were made on proposed irrigation and drainage projects.

Additional Investigation Needed.

The work of all projects at present under way is incomplete in that it lacks in much detailed information necessary to fit the definite facts established into farm management practice. The stations at Pullman, Lind, Waterville and Prosser offer splendid opportunities to gain this information on definite soil types under different climatic conditions. Much information is still lacking on the following points which have a direct bearing on the permanency of agriculture; the part played by free nitrogen fixation; the possibilities of nitrogen fixation by legumes; the best use of barnyard manure and crop residues; the results of various rotation systems and the classification of soils from the standpoint of plant food requirements.

Soil surveys in co-operation with the U. S. Department of Agriculture should be made of the more important agricultural areas of the state. Many other problems, such as the best use of irrigation water for various crops, development and management of march soils, the improvement of soils on cut-over lands, the use of lime in Western Washington and land drainage in the Palouse, in irrigated Washington and Western Washington merit early attention.

DIVISION OF VETERINARY SCIENCE

J. W. Kalkus, in Charge

Goitre and Associated Conditions in Domestic Animals.

Co-operative field experiments with live stock owners in goitrous districts, which were started a year ago, have been continued during the season 1919-20.

Reports thus far received further demonstrate that the administration of iodine to all species of domestic animals during pregnancy can be depended upon to prevent goitre and hairlessness in the newborn. Our data on the use of iodine in the prevention of this malady are sufficient to warrant discontinuance of this work.

Popular Bulletin No. 117, entitled "The Prevention of Goitre (Big Neck) and Hairlessness of Newborn Domestic Ani-

mals," was published in October, 1919. A technical bulletin fully illustrated and dealing in detail with a description of the disease and the results of experimental work is just off the press.

Orchard Horse Disease.

This disease, which is causing serious loss among horses in the irrigated orchard districts of Washington, has been given considerable attention during the year. The condition has been studied in the field clinically, a number of autopsies have been performed and several experiments conducted at the experiment station at Pullman.

It is the general belief that orchard horse disease is due to arsenate of lead poisoning. Thus far in the experimental work, three horses have died after being fed arsenate of lead in varying quantities daily. From the symptoms and post mortem lesions found in these animals, it is not possible to state definitely that arsenate of lead spray is responsible for orchard horse disease. This work is being continued and further feeding experiments will be conducted with orchard grown hay. One normal horse has also been inoculated with blood serum taken from a typical case of orchard horse disease. The results were negative.

Red Water (Cystic Haematuria) in Cattle.

The study of this disease, which was discontinued in 1913, was again resumed in June, 1920. Since then the Veterinarian has visited Thurston, King, Kitsap, Island, Snohomish and Whatcom Counties and started co-operative experiments in the treatment of this trouble. At the present time there are forty-five cows under treatment. Arrangements have been made to keep in touch with the progress of the work through County Agents in the various counties.

ADAMS BRANCH EXPERIMENT STATION

M. A. McCall in Charge

Most of the fundamental studies of dry farming have centered on moisture conservation. This is essential, but the time

is coming when additional knowledge looking to the development of a permanent system of dry farming agriculture must be secured or much land that is now profitably farmed will be lost to production. Studies must be broadened to include more than simple moisture relationships.

Tillage is important because of its influence on the absorption and retention of moisture, yet the effects on the availability of plant food, and the consequent efficiency of moisture usage are almost as important. This is especially true now that dry farm soils are beginning to show a depletion in their virgin fertility.

The following table gives limited data from the summer fallow tillage experiments of the Adams Station, indicating how variation in date of plowing affected moisture, available nitrogen, yield and quality of the crop in the year 1919:

Date of Plowing	Water, in tons, acre	Nitrates, in lbs., acre	Yield per Acre		Weight per bushel
			Grain bushels	Straw pounds	
March 1 ..	660.4	246.4	12.3	730	58.0
April 10 ..	655.4	200.2	12.5	650	58.2
June 1 ...	636.0	161.6	11.6	590	58.9

These data indicate that while there is a slight moisture advantage in favor of the early plowing, the greatest difference is in the effect on available nitrogen. Grain yields are not materially affected by this difference, but straw yields greatly favor the early work and in a season of more abundant rainfall than 1919, grain yields also undoubtedly would have been increased. The result does indicate a more efficient use of the moisture supply in the case of the more liberal plant food supply.

It might be objected that such production is poor economy, resulting in an increase of cheap straw without a corresponding increase in the quantity of the more valuable grain. If no use is to be made of the straw, as has largely been the case in the past, such a contention is correct. This has been one of the great weaknesses of dry farming methods. Through depletion of soil organic matter, numerous and serious problems are arising, and something must be done toward their solution. Other studies at the Adams Station indicate that the use of

straw and barnyard manure, properly handled, will go a long way toward the correction of such difficulties.

Adaptational and other experiments on the Adams Station are being carried as heretofore. Results from cereal variety tests are similar to those reported previously, Early Baart, Washington 618, still being the leading spring wheat variety and Turkey Red, Washington 326, the leading winter wheat variety.

THE WATERVILLE BRANCH STATION

C. E. Hill, in Charge

The investigations on the Waterville Branch Station are conducted in co-operation with the Office of Forage Crop Investigations of the U. S. Department of Agriculture.

The Station Farm consists of 215 acres and is divided into two tracts of 55 and 160 acres, respectively. These farms are one-half mile apart. The smaller tract adjoins the County Fair Grounds and the city limits of Waterville. All land is leased. There is a good building on the 55-acre farm which is used for general storage of supplies, seeds and machinery. On the large farm there is an old house and log barn. Both buildings are in very poor condition. The Station owns four good horses and is well equipped with farm machinery.

This Branch Station is located in an area where the conditions are about intermediate between the conditions at the Adams Branch and the Pullman stations. Wheat is grown almost exclusively, alternating with summer fallow. The annual precipitation at Waterville for a 30-year period is about 12.5 inches. As this section will probably never be able to turn to irrigation to solve the problem of building up a soil that may become unproductive from continuous cropping to grain, the determination of profitable methods of dry farming that will maintain or increase the productivity of the soils, has been given special emphasis in planning the work of this station.

To meet the immediate needs of this section, an attempt is being made to determine the best varieties of grains and to

distribute pure seed of these varieties among the farmers. About 50 grain varieties that have shown promise in other dry land sections are being tested. As there is no general agreement among farmers as to the most profitable systems of handling the summer fallow in any section of the county, all the methods in vogue in this area are being tried on the station for the production of winter and spring grains.

Because of varying climatic conditions from year to year, these investigations should be conducted for a series of years before any definite conclusions are drawn. The past season has been the driest on record for this section.

WASHINGTON IRRIGATION EXPERIMENT STATION

R. P. Bean in Charge

Development by the Washington Irrigation Branch Station of 200 acres of sage brush land was begun on May 1, 1919. Irrigation water was delivered for the first crop, 37 acres of wheat, on May 24. As rapidly as the land was prepared and the irrigation system installed, 16 acres were planted to potatoes, 15 to corn and 10 to millet. Clearing the land of sage brush, leveling and fluming for irrigation was continued throughout the summer. Beginning early in August, 38 acres of wheat stubble and new land were seeded to alfalfa, 50 acres were seeded to alfalfa and wheat and 10 to alfalfa and rye. Sweet clover was seeded in nine acres of corn, and rye on 10 acres following potatoes. A total of 78 acres were thus put in spring and summer crops. The fall seeding brought the total acreage cropped or in crop to 138. With the co-operation of the U. S. Reclamation Service, irrigation water was available until all the land in crop had been thoroughly irrigated on October 18.

The season of 1920 opened for farm work on January 20. The fall seeded crops were in excellent condition, with the exception of some September wind damage to alfalfa, 30 per cent winter killing of 10 acres of Bluestem wheat and some of the winter grain variety plots.

Between January 20 and April 1, 38 acres of new land were plowed and 24 acres were spring-toothed. Twenty-four acres were prepared for irrigation and seeded to rye. Seven acres of 1919 wheat stubble were seeded to rye. The deliveries, flumes and head ditches were put in order. The heavy snow of the preceding winter had filled the soil with plenty of moisture and plans were made to put the total remaining uncropped area of 56 acres in crop this season.

On April 1st, the unusually heavy wind which had been blowing almost constantly for 20 days ripened into a severe two-day wind storm. During these two days from one to four inches of soil were removed from the light soil area of the farm and the erosion and the cutting action of drifting sand had materially damaged the crops on the heavier soil area.

A careful survey on April 6 established the following facts: Twenty-six acres of winter wheat, including the winter grain variety plots, had been blown out; 24 acres of winter wheat were damaged from 25 to 65 per cent; 10 acres of winter rye had suffered by 30 per cent; the alfalfa in 60 acres of winter grain was damaged 90 per cent; 20 acres of alfalfa seeded in wheat stubble was injured 75 per cent; 24 acres of spring seeded rye would be a 75 per cent stand, and the nine acres of sweet clover would be a patchy stand. The soil moisture was so depleted that the remaining crops demanded immediate and thorough irrigation. Irrigation would also be necessary to germinate new seeding and irrigation before seeding seemed a desirable check to further damage by wind.

Chiefly because of the immediate irrigation requirement of the fields in crop, plus the unexpected task of reseeding the wind damaged fields and the extra water requirement of these fields by virtue of reseeding, the seeding program for the remaining new land was at first postponed and finally abandoned until fall. In addition to these two developments and crop limiting factors, i.e., wind storm and decreased acreage in crop, the insufficient supply of irrigation water during the growing season and a break in the canal which shut off all

water for a week in July, were additional obstacles to the program of production.

To provide a dependable source for both domestic and stock water, a 160-foot well was drilled this season and supplied with pumping, storage and distributing equipment. A quarter-mile of jack rabbit proof fence was built which, connecting with like fences to the west and to the east and north, effectively protected this season's crops against these numerous pests. Twenty-five acres of pasture were fenced and cross fenced. One-eighth mile of fence was built on the north side which connects with existing fences to complete the north line. A wooden-hoop single-wall silo was built with farm labor for this year's silage crop.

The potato experimental work, under the direction of the Division of Horticulture of the Experiment Station, begun in 1919, was continued this season and will receive increased attention as the station develops. Beginning with 1921, fertilized land and fields on which legumes have been grown will be available for this work.

The small grain and forage crop experimental work, under the direction of the Department of Farm Crops of the Experiment Station, and in co-operation with the Office of Forage Crops of the U. S. Department of Agriculture, which was begun with alfalfa and winter grain variety tests in 1919, was increased this season and will be on a definitely helpful scale next year. Six varieties of alfalfa were seeded this spring, as were also varieties of spring wheat, barley and oats. Five varieties of soy beans and two of cow peas made good crops for the soil on which they were grown and the seed secured will be used for continued planting.

The Mammoth Russian sunflowers grown for silage this year made better growth on the new land than corn, and seed was selected for future planting.

Winter wheat and rye, where the stands were at all comparable, yielded better than spring wheat and rye and required less irrigation this season. The problem of a second crop following small grain, particularly winter grain because it is harvested so early in the season, on new land which often

becomes overgrown with Russian thistles, when not in crop, merits attention, both for weed control and for maximum production.

Field peas, seeded alone and with wheat, made a good growth and a fair seed crop. A second pea crop, secured by harrowing in the shattered seed and irrigating immediately, made a twelve-inch growth, with many plants in blossom before frost on October 2. It is possible that by very early planting, two crops of pea hay could be secured in one year.

As rapidly as the development of the land permits, definite areas will be set aside for experimental work in the use of water, in soil management, in varietal work with forage, grain and seed crops and for horticultural investigations. Pasture studies and feeding trials in the utilization of home-grown feeds will be emphasized.

THE OFFICE OF FARM MARKETS

Joseph Passoneau, in Charge

The Office of Farm Markets was created by an act of the State Legislature during the session of 1917. In carrying on its work, the Office attempts to co-operate fully with the Extension Department of the College, especially the County Agent staff, the State Department of Agriculture, and the Bureau of Markets of the U. S. Department of Agriculture. The Federal Bureau of Markets co-operates not only in the work done, but pays a part of the salary of the Director of Markets.

The activities of the Office as provided by law and carried out by the Director of Markets fall under four general heads: (1) assistance in co-operative organization; (2) research in marketing; (3) market news service, and (4) general extension work in marketing.

Co-operative Organization.

During the first two years of the existence of the Office of Markets, twelve co-operative associations were formed. Ten such associations have been formed in the past eighteen months

with the assistance and guidance of the Office. They are as follows:

The San de Fuca Co-operative Dock Association, San de Fuca.

Grays Harbor County Dairy Association, Montesano.

Pierce County Milk Producers Association, Tacoma.

Kitsap County Dairymen's Association, Silverdale.

Yakima Valley Potato Growers' Association, Toppenish.

Toledo Co-operative Cheese Factory, Toledo.

Newport Creamery Association, Newport.

The Pacific Cranberry Exchange, Ilwaco.

The Gig Harbor Co-operative Association, Gig Harbor.

Inland Empire Dairy Producers Association.

In addition considerable assistance has been given in the organization of the Washington Wheat Growers Association. Altogether representatives of the Office during the past eighteen months have spoken before 121 meetings and attended 382 conferences having to do with subjects of marketing. No record was kept the first six months of this biennium of the number of persons attending these meetings. Including all of the meetings held during the past year, 4065 farmers have been addressed by representatives of the Office on the subject of co-operation in marketing.

Research in Marketing.

During the first six months of the present biennium, the Office was without a research man. Consequently active research in marketing has been carried on only during the past year. An intensive study of the marketing of milk through condenseries has been in progress since last November and the results of this work will be ready for publication in November. Last July work was commenced upon an investigation of the city marketing of milk in Seattle. It is expected that the results of this study will be ready for the press about January.

Market News Service.

The Office has a monthly publication, the "Monthly Market Exchange," which in addition to items of local market

news carries lists of various farm products for sale by farmers of the state. This publication is distributed to about 15,000 addresses.

A directory of breeders of pure bred live stock in the State of Washington, including breeders of cattle, horses, sheep and swine, has been prepared. The directory includes eight full page charts showing the distribution of the various breeds of pure bred stock in the state. In addition, photographic representations of various pure bred animals are shown. Tables showing the number of pure bred animals in each county as well as the number for sale by counties are included.

General Extension Work.

Representatives of the Office are occasionally called upon for addresses upon various marketing subjects at general meetings of farmers. During the past two years many such addresses have been made.

PUBLICATIONS

The following publications were prepared by members of the Experiment Station Staff and published during the year:

General Bulletins.

- 155 Twenty-ninth Annual Report.

Popular Bulletins.

- 117 The Prevention of Goitre (Big Neck) and Hairlessness of Newborn Domestic Animals, by J. W. Kalkus.
118 The Cost of a Squirrel and Squirrel Control, by W. T. Shaw.
119 Head Smut of Corn and Sorghum, by B. F. Dana and Geo. L. Zundel.
120 Prune Growing in Western Washington, by O. M. Morris.

Bulletins.

- 61 The Woolly Aphid of the Apple, by A. L. Melander.
64 Apple Anthracnose or Black Spot Canker, by F. D. Heald.

Entomology Circular.

- 20 The Orchard Leaf Roller.

FINANCIAL STATEMENT
WASHINGTON AGRICULTURAL EXPERIMENT STATION
in account with
THE UNITED STATES APPROPRIATIONS, 1919-1920

Dr.		Hatch	Adams
Receipts from the Treasurer of the United States as per appropriations for fiscal year ended June 30, 1920, under acts of Congress approved March 2, 1887 (Hatch Fund), and March 16, 1906 (Adams Fund)			
		\$15,000.00	\$15,000.00
Cr.		Abstract	
Salaries	1	\$ 9,485.57	\$11,606.08
Labor	2	3,353.03	1,870.90
Publications	3	.....	.....
Postage and stationery	4	32.10	13.47
Freight and express	5	5.32	.....
Heat, light, water and power	6	12.15	.....
Chemicals and laboratory supplies	7	7.44	311.55
Seeds, plants, and sundry supplies....	8	525.36	340.98
Fertilizers	9	106.49	.....
Feeding stuffs	10	13.40	.....
Library	11	.....	.....
Tools, machinery and appliances	12	156.47	2.70
Furniture and fixtures	13	326.15	69.50
Scientific apparatus and specimens...14		2.50	579.62
Live stock	15	.....	.....
Traveling expenses	16	966.52	205.20
Contingent expenses	17	.....	.....
Building and land	18	7.50	.....
Total		\$15,000.00	\$15,000.00

FINANCIAL STATEMENT

State Funds Expended on Main Station and All Branch Stations
(Excepting the Western Washington Station, which is operated independently)

April 1, 1919, to March 31, 1920

	Dr.	State Appropriations	Sales	Total
To balance on hand			\$ 1,056.36	\$ 1,056.36
Receipts from other sources than the U. S. for the year ended		\$70,245.94	20,415.06	90,657.00
Total		\$70,243.94	\$21,469.42	\$91,713.36
Cr.				
Salaries		\$14,501.15	\$ 1,170.00	\$15,671.15
Labor		15,964.65	4,598.24	20,562.89
Publications		67.45	635.40	702.87
Postage and stationery		681.22	834.33	1,515.55
Freight and express		718.35	159.95	878.30
Heat, light, water, power.....		1,238.04	16.00	1,254.04
Chemicals and laboratory supplies		350.01	527.13	877.14
Seeds, plants, sundry supplies.		5,250.97	1,412.84	6,643.81
Fertilizers		2,119.32	33.86	2,153.18
Feeding stuffs		2,348.74	993.40	3,342.14
Library		172.75	71.64	244.39
Tools, machinery & appliances		3,723.34	621.09	4,344.43
Furniture and fixtures		1,612.74	141.00	1,853.74
Scientific apparatus and specimens		610.67	81.33	692.00
Live stock		5,585.00	2,649.00	8,234.00
Traveling expenses		1,847.71	391.04	2,238.75
Buildings and land		13,471.81	940.36	14,412.17
Balance			6,192.81	6,192.81
Total		\$70,243.94	\$21,469.42	\$91,713.36

FINANCIAL STATEMENT

Western Washington Station*

April 1, 1919, to March 31, 1920

	Dr.	State Appropriations	Sales	Total
To balance on hand			\$ 4,780.91	\$ 4,780.91
Receipts		\$116,332.21	22,630.15	138,962.36
		<u>\$116,332.21</u>	<u>\$27,411.06</u>	<u>\$143,743.27</u>
Cr.				
Salaries	\$ 13,375.94		\$ 8,534.85	\$ 21,910.79
Labor	12,393.31		6,338.51	18,731.82
Publications	4,965.31			4,965.31
Postage, stationery, tele- phone & telegraph	848.35			848.35
Freight and express	202.60			202.60
Heat, light, water & power.	845.40			845.40
Chemical supplies	134.74			134.74
Seeds, plants & sundry sup- plies	1,459.94			1,459.94
Fertilizers	105.69			105.69
Feeding stuffs	8,649.30			8,649.30
Library	39.56			39.56
Tools, machinery & appli- ances	4,009.89			4,009.89
Furniture & fixtures	222.53			222.53
Scientific apparatus & speci- mens				
Live stock	176.50			176.50
Traveling expense	982.09			982.09
Contingent expenses				
Buildings & land	67,921.06			67,921.06
Balance			12,537.70	12,537.70
		<u>\$116,332.21</u>	<u>\$27,411.06</u>	<u>\$143,743.27</u>

*The report of the work of the Western Washington Station, which is operated independently, is not included in this report.

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**STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON**

DIVISION OF FARM CROPS

Wheat Production

AS INFLUENCED BY

Variety, Time of Seeding, and Source of Seed

By

E. G. SCHAFER, E. F. GAINES and O. E. BARBEE

BULLETIN No. 159

March, 1921

**All Bulletins of this Station are sent free to citizens of the State on
application to the Director**

BOARD OF REGENTS

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W. I. Nightingale, B. S.	Assistant in Bacteriology
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Henry Holtz, M. S.	Assistant in Soils
J. W. Kalkus, D. V. S.	Veterinary Science

M. A. McCall, B. S. **	Superintendent Lind Branch Station
C. E. Hill, B. S.**	In charge Waterville Branch Station
R. P. Bean, B. S. **	Superintendent Washington Irrigation Station

*On leave.

**In co-operation with the United States Department of Agriculture.

***In co-operation with Chelan County.

DEC 10 '36

CULTURAL EXPERIMENTS WITH WHEAT *

By

E. G. Schafer, E. F. Gaines and O. E. Barbee

The cultural experiments with wheat were started in 1899 on field six. This field which is also known as the Spillman Field contains 28 plots and is divided into two groups, the A series on the north, and the B series on the south. There is a roadway around the field and between the two series. The plots are separated by alleys five and two-thirds feet wide, and are 20 by 66 feet, or one-thirty-third of an acre in size. The plots are numbered consecutively from east to west. The field occupies the lower portion of a south slope and the soil is a typical Palouse silt loam. Figure 1 shows the location and contour of the plots.

It will be seen from the various tables pertaining to the cultural experiments that certain of the records, especially during the earlier years, have not been included. In 1905 the wheat contained so much smut that it was all cut for hay. In 1913 the winter wheat again contained a large amount of smut and was not harvested for grain. Other records have been omitted because of irregularities in cropping.

The general plan of the cultural experiments with wheat is somewhat restricted in character yet the records obtained supply valuable information concerning certain questions relating to tillage and crop rotation. It is not expected that the results given will be equally applicable under varying conditions, of soil and climate. They should, however, be of general value in pointing out superior methods over a considerable portion of the area of the state devoted to wheat and of special value to conditions similar to those of Pullman, Washington.

* The experiments reported in this bulletin were planned before many of the present tillage and rotation problems were apparent. The conclusions reached, therefore, deal only with a few of the important tillage problems.

The experiments were planned and started by W. J. Spillman and for a number of years the work was carried on by E. E. Elliot and George Severance.

PLAN OF THE EXPERIMENTS

The field contains six separate experiments. The cropping practices of the different plots are given below:

I. Application of Manure.

- A 1, ten tons of manure per acre plowed under each fall, winter wheat annually.
- A 2, ten tons of manure per acre plowed under in the spring of fallow year, winter wheat even years.
- A 3, ten tons of manure per acre plowed under each spring, spring wheat annually.
- A 4, ten tons of manure per acre used as a top dressing on summer fallow odd years, winter wheat even years.
- A 5, ten tons of manure per acre used as a top dressing in winter after wheat is up, summer fallow odd years, winter wheat even years.

II. Summer Fallow Methods.

- A 6, plow early in spring, till well, winter wheat odd years.
- A 7, plow late in spring, till little, winter wheat odd years.
- A 8, plow very shallow early in spring, deep later after weeds have started, till well after second plowing, winter wheat odd years.
- A 9, plow very shallow early in spring, deep later after weeds have started, no tillage after second plowing, winter wheat odd years.

III. Time of Seeding Wheat.

- A 11, seed in early fall, winter wheat each year.
- A 12, seed in medium fall, winter wheat each year.
- A 13, seed in late fall, winter wheat each year.
- A 14, seed in early spring on fall plowing, spring wheat each year.

IV. Wheat in Rotation.

- A 10, five years rotation,—corn, winter wheat, clover 2 years, oats and peas.
- B 1, two year rotation,—corn, winter wheat.
- B 2, four year rotation, ten tons manure divided between four crops,—clover and timothy 2 years, oats, corn.

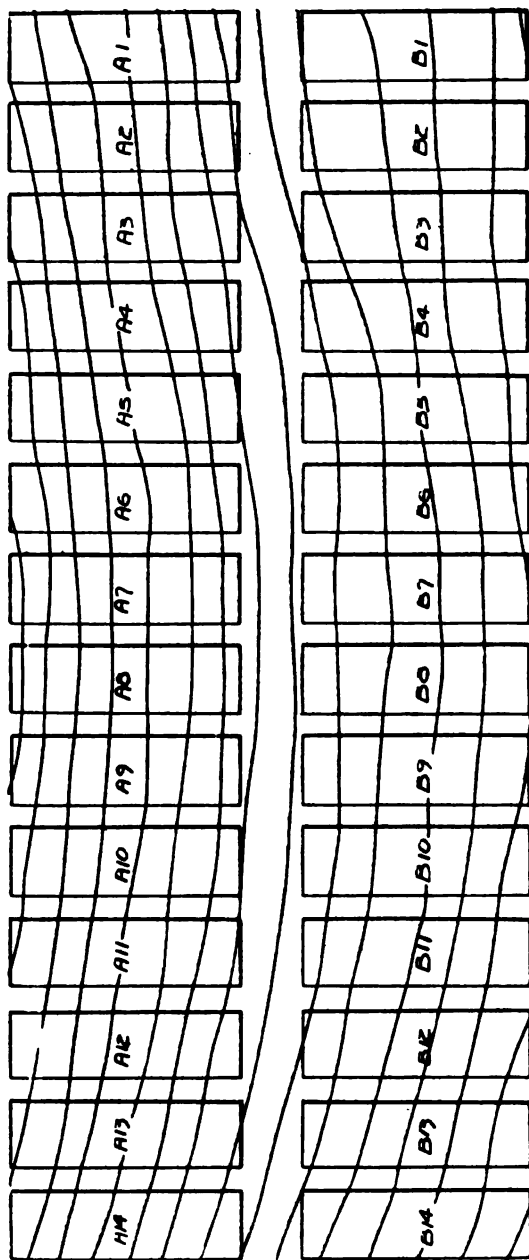


Fig. 1. Contour map of the Spillman plots of Field VI. Contour interval 2 feet.
These plots have been cropped according to the outline for experimental purposes
since 1899.

B 3, five year rotation,—winter wheat, oats, clover and timothy 2 years, corn.

B 4, six year rotation,—clover and timothy 3 years, oats and peas, corn, winter wheat.

B 5, five year rotation,—corn, winter wheat, clover and timothy 2 years, oats and peas with 10 tons manure plowed under for oats and peas.

B 6, four years rotation,—corn, winter wheat, mangels, oats, plow under 10 tons manure per acre for corn.

B 11, four year rotation,— corn, winter wheat, mangels, peas,

V. Fall and Spring Plowing for Spring Wheat.

B 7, plow in spring 7 inches deep, spring wheat each year.

B 8, plow in fall 7 inches deep, spring wheat each year.

VI. Depth of Plowing for Spring Wheat.

B 9, plow in spring 8 inches deep even years, 5 inches deep odd years, spring wheat annually.

B 10, plow in spring 5 inches deep even years, 8 inches deep odd years, spring wheat annually:

B 12, plow in spring 4 inches deep each year, spring wheat annually.

B 13, plow in spring 6 inches deep each year, spring wheat annually.

B 14, plow in spring 8 inches deep each year, spring wheat annually.

Wheat was grown annually on the plots used for the investigations on time of seeding wheat. A suitable seed bed could not be prepared every year in time for the early fall seeding because of the dry hard soil. It was thus impossible to conduct this experiment in accordance with the plans, and the results, therefore, have not been given. The results of another experiment on date of seeding winter wheat, in which the crop was planted on summer fallow, are contained in Washington Experiment Station Bulletin 159.

APPLICATION OF MANURE

Table I contains the yield of spring and winter wheat when a crop was grown each year with and without manure, also the yields of winter wheat grown alternating with summer fallow when manure was applied at different times, during the year. Plot A 3 was manured each spring at the rate of 10 tons per acre, after which the land was plowed and seeded to spring wheat. Plot A 14 was treated in the same manner as A 3, except that it did not receive an application of manure. Plot A 3 produced an average of 24.7 bushels per acre for 12 crops and plot A 14 produced an average of 22.5 bushels, or a difference of 2.2 bushels per acre in favor of the manured plot.

Plot A 1 was manured each fall at the rate of 10 tons per acre, after which the land was plowed and seeded to winter wheat. Plot A 11 was treated in the same manner as A 1, except that it did not receive an application of manure. A 1 produced an average of 32.9 bushels and A 11 produced but 18.7 bushels, or a difference of 14.2 bushels per acre in favor of the manured plot. While an annual application of manure increased the yield of both spring and winter wheat, a greater increase of 12 bushel was obtained by plowing manure under in the fall for winter wheat than by plowing it under in the spring for spring wheat.

The manner of applying manure has had but little influence on yield of winter wheat grown on summer fallow land. There is a variation in yield of 1.3 bushels per acre for an average of six crops for the different methods of application.

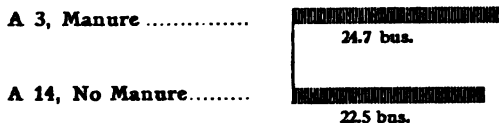
The plots on which this experiment was conducted were in wheat during even years and in summer fallow during odd years. The plots were all plowed in the spring, usually the latter part of May of the summer fallow year. They all received an application of manure at the rate of 10 tons per acre for each crop. The manure was applied before plowing on plot A 2, after plowing and before seeding on plot A 4, and it was applied after seeding during the early winter on plot A 5. By referring to Table I it will be seen that plot A 2, on which manure was applied before plowing, produced an average of 38.7 bushels, plot A 4, which received the

Table I. Effect of Manure on Yield of Wheat
(Acre yield in bushels.)

YEAR	Spring wheat annually			Winter wheat annually			Winter wheat alternating with summer fallow		
	A 3 Manure plowed un- der each spring	A 14 No manure	A 1 Manure plowed un- der each fall	A 11 No manure	A 2 Manure plowed under in spring of fallow year	A 4 Manure put on fallow in summer	A 5 Manure put on wheat in early winter		
1906	11.0	16.4	31.3	22.5	27.5	26.4	41.2		
1907	48.4	25.8	51.7	24.7					
1908	16.5	22.0	37.9	13.7	49.5	53.3	57.2		
1909	45.6	31.3	28.3	30.2					
1910	27.7	26.1	22.5	14.0	37.4	34.9	33.5		
1911	13.7	20.9	30.8	20.9					
1914	20.7	25.3	38.1	13.2	36.0	50.4	49.0		
1915	8.1	9.6	29.1	20.6					
1916	22.2	34.6	21.0	1.6	44.1	40.2	40.4		
1917	27.2	15.7	31.5	11.8					
1918	23.2	16.8	32.4	16.8	37.7	31.9	18.7		
1919	32.4	27.2	40.1	34.4					
Aver.	24.7	22.5	32.9	18.7	38.7	39.5	40.0		

manure as a top dressing after plowing, produced 39.5 bushels, and plot A 5, which received a top dressing of manure after the seed was planted, produced an average of 40.0 bushels.

Spring wheat each year:



Winter wheat each year:



Fig. 2. Manure applied to spring and winter wheat when wheat was grown on the same land each year,—12 year average. The use of manure increased the yield of winter wheat 14.2 bushels per acre, while spring wheat was increased only 2.2 bushels. When manure was not used winter wheat produced 3.8 bushels less than spring wheat. The greatest value of manure was obtained by plowing it under in the fall for winter wheat.

Unfortunately there was no plot of wheat alternating with summer fallow not receiving manure which can be directly compared with these plots. Plot A 6, Table II, however, was devoted to wheat alternating with summer fallow, but it was in wheat during the odd years while the three plots receiving manure were in wheat during

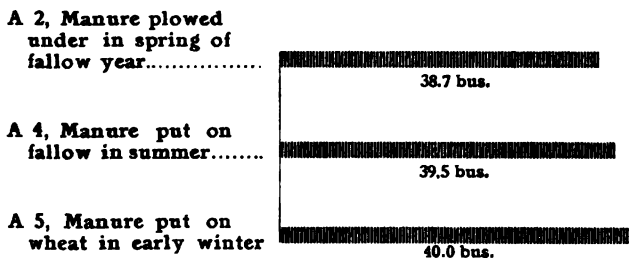


Fig. 3. Methods of applying manure for winter wheat grown on summer fallow land,—average for six crops. A difference of 1.3 bushels per acre resulted in applying manure before plowing, as a top dressing after plowing, and as a top dressing after seeding.

even years. Plot A 6, which was plowed early and tilled well, produced a yield of 46.6 bushels for the average of six crops. The average yield of the six crops of wheat for the three plots receiving manure was 39.4 bushels per acre. Before a comparison is made between the plot not receiving manure and the plots receiving manure, the character of the season as effecting wheat production should be taken into consideration.

According to the yearbooks of the United States Department of Agriculture, the average yield of winter wheat in the state of Washington for the same period (odd years) as reported for A 6, was 25.3 bushels per acre. The average yield, for the period (even years) during which the manured plots produced wheat, was 24.3 bushels per acre.

That the odd years have been more favorable for wheat production is also shown in plots A 1 and A 11 which have been in winter wheat each year. The average yield of these two plots for the odd years of this period is 29.5 bushels while the average yield for the even years is 22.1 bushels per acre. There has thus been a difference of 7.4 bushels per acre in this particular field in favor of the odd years where winter wheat was grown continuously with and without manure.

If the increase in yield of 7.4 bushels per acre during the odd years in plots A 1 and A 11 be attributed to the seasonal factor and if the use of manure on plots A 2, A 4, and A 5 did not influence the yield, it would be expected that plot A 6 being cropped during odd years would outyield A 2, A 4 and A 5 since they were cropped during even years. The average yield of A 6 is actually 7.2 bushels greater than the average of A 2, A 4, and A 5. If allowance were made for the higher yields of odd years obtained in this manner, it would appear that manure when applied at the rate of 10 tons per acre will not materially effect the yield of wheat when grown alternating with well tilled summer fallow.

SUMMER FALLOW METHODS

An average of 11.8 bushels more wheat was produced by early and thorough tillage of summer fallow than by plowing the land late and leaving it untilled. These results were obtained on plots A 6 and A 7 which were cropped to winter wheat alternating with summer fallow. Plot A 6 was plowed early in the spring each summer fallow year. It was tilled sufficiently to keep it free from weeds and to maintain a soil mulch. Plot A 7 was plowed in the late spring after the surface soil became dried out. The land was left rough and only enough tillage given to destroy the weeds. In general, weeds showed but little tendency to grow on this plot and the soil became dry to the depth plowed. Both plots were prepared for seeding in the fall and seeded to winter wheat at the same time. Table II contains the



Fig. 4. Result of early and late summer fallowing. The plot on the left which was plowed early and tilled well produced at the rate of 57.2 bushels per acre in 1919. The one on the right which was plowed late and tilled little produced 40.1 bushels.

yield of the six crops which were grown on these plots. It shows that the early plowed, well tilled summer fallow produced an average of 11.8 bushels per acre more than the plot which was plowed late and tilled little. These results are in accord with the practices and beliefs of the best farmers in the state wherever wheat is grown alternating with summer fallow.

Table II. Effect of Early and Late Plowing of Summer Fallow on Yield of Winter Wheat
(Acre yield in bushels.)

YEAR	A 6	A 7	Difference in favor of early plowing
	Plowed early tilled well	Plowed late tilled little	
1907	40.1	27.5	12.6
1909	64.3	50.6	13.7
1911	62.2	40.0	22.2
1915	39.6	32.1	7.5
1917	16.5	18.7	-2.2
1919	57.2	40.1	17.1
Aver.	46.6	34.8	11.8

The kind of tillage given plot A 6 not only conserved moisture but was effective in keeping more moisture close to the surface. These conditions also promoted the development of plant food during the summer which was impossible to the same extent in plot A 7 with its lower moisture content.

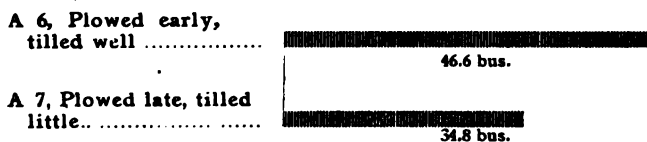


Fig. 5. The early well tilled summer fallow produced 11.8 bushels more wheat for an average of six crops than the plot which was plowed late and tilled little.

WHEAT IN ROTATION

Table III gives the wheat yields for seven plots in which wheat has been grown in rotation, one plot which grew winter wheat annually, one plot spring wheat annually and one plot cropped to winter wheat alternating with summer fallow. The names of the other crops in the rotation are inserted in the table at the places they occur.

The average yield of wheat is given for each plot for the years it was in wheat, and in addition, the average yields for the first half

Table III. Wheat Grown in Various Rotations
(Acre yield in bushels)

YEAR	A 6	A 10	A 12	B 1	B 3	B 4	B 5-10T manure	B 6-10T manure	B 11	B 13
1899	s. wheat	corn	20.9	23.4	36.3	40.7	corn	22.0	32.4	34.1
1900	s. fallow	33.8	28.6	corn	oats	corn	30.5	roots	roots	11.6
1901	61.9	clover	23.0	47.3	clover	41.3	clover	barley	peas	34.7
1902	84.7	clover	34.7	corn	clover	clover	clover	corn	corn	39.1
1903	20.9	peas - oats	9.9	18.7	corn	clover	oats - peas	28.6	35.7	38.5
1904	s. fallow	corn	20.3	corn	51.7	clover	corn	roots	roots	21.4
1905	wheat hay	w. hay	20.3	w. hay	oats	oats - peas	w. hay	oats	peas	w. hay
1906	s. fallow	clover	22.5	corn	clover	corn	33.5	corn	corn	28.6
1907	40.1	clover	22.5	44.5	clover	58.8	clover	37.4	34.6	42.9
1908	s. fallow	peas - oats	16.5	corn	corn	clover	oats - peas	roots	roots	26.9
1909	64.3	corn	28.6	63.8	50.6	clover	corn	oats	peas	39.0
1910	s. fallow	28.6	15.1	corn	oats	clover	40.7	corn	corn	34.4
1911	62.2	clover	23.6	59.9	clover	oats - peas	clover	56.1	66.0	8.2
1912	s. fallow	clover	27.5	corn	clover	corn	clover	roots	roots	39.0
1913	wheat hay	peas - oats	16.2	w. hay	corn	w. hay	oats - peas	oats	peas	23.6
1914	s. fallow	corn	16.2	corn	52.8	clover	corn	corn	corn	16.5
1915	39.6	33.0	21.7	45.4	oats	clover	46.9	39.3	43.4	11.8
1916	s. fallow	clover	8.5	corn	clover	clover	clover	roots	roots	39.9
1917	16.5	clover	3.8	38.5	clover	oats - peas	clover	oats	peas	29.1
1918	s. fallow	peas - oats	16.8	corn	corn	corn	oats - peas	corn	corn	27.2
1919	57.3	corn	29.1	61.3	57.2	52.3	corn	58.0	58.8	35.7
Average	44.2	31.8	20.5	44.8	49.7	48.3	37.6	40.2	45.1	29.1
Average '99 to '09	44.4	33.8	22.7	39.5	46.2	46.7	32.0	29.3	34.2	31.7
Average '10 to '19	43.9	30.8	18.0	51.3	55.0	52.2	43.3	51.1	50.1	26.5

of the period and those for the second half of the period, are given separately.

It will be seen that the average wheat yields are greater during the second period than the first, for four of the five plots in which wheat is grown in rotation with a legume. The average yield is slightly lower during the second period on plot A 10 but it has a record of only three yields. Plot B 1 which was cropped to wheat and corn alternating also produced a larger yield during the second period of the rotation. Considering the character of the rotation this yield is larger than would be expected. Attention should be called to the fact, however, that B 1 is located so that it may have drainage from A 1 which was given an application of manure each fall equivalent to 10 tons per acre. It is possible that the yield on plots B 3, B 4 and B 5 were increased for a similar reason.

The yields on plot A 12 which grew winter wheat annually and B 13 which grew spring wheat annually, are considerably lower for the second than for the first period. Plot A 6 which was cropped to wheat alternating with summer fallow produced approximately the same yield for both periods of the rotation.

The wheat yields when grown in rotation, in general, have been on the increase while those plots which grew wheat continuously have suffered a decrease in yield.

No attempt has been made to analyze and explain all of the causes for the results shown in the table, since the various plots have not been in wheat the same number of times, and certain seasons have been more favorable for wheat production than others. The reader is invited to place his own interpretations on the results given in the table, but it is believed he will find sufficient evidence to assure him that a rotation of crops including legumes, and the use of manure, will aid in maintaining the productiveness of the soil.

FALL AND SPRING PLOWING FOR SPRING WHEAT

According to Table IV, a larger yield of spring wheat was obtained on spring plowing than on fall plowing during ten out of fourteen years, and the average for the fourteen years on spring plowing ex-

Table IV. A Comparison of Fall and Spring Plowing for Spring Wheat

(Acre yield in bushels.)

YEAR	B 7	B 8
	Plowed in spring	Plowed in fall
1906	20.9	19.8
1907	37.9	31.9
1908	29.1	25.8
1909	45.4	47.2
1910	28.3	27.5
1911	17.6	11.0
1912	36.8	28.3
1913	22.0	28.0
1914	17.3	20.1
1915	14.6	8.0
1916	41.8	32.3
1917	25.6	17.6
1918	19.5	17.0
1919	31.9	33.8
Aver.	27.8	24.9

ceeded that on fall plowing by 2.9 bushels per acre. Plot B 7 was plowed in the spring each year as soon as the land was in condition. B 8 was plowed the previous fall and disked in the spring. Both plots were harrowed just before seeding and seeded at the same time. The spring plowed plot produced an average of 27.8 bushels and the fall plowed plot an average of 24.9 bushels or a difference of 2.9 bushels per acre. While the spring plowed land produced somewhat the larger yield, spring plowing has the disadvantages of delaying spring seeding. Early spring seeding is generally considered preferable to late spring seeding and if a considerable area is to be seeded in the spring it is desirable to have as much of the land plowed in the fall as possible in order that seeding may be completed in the early spring.

It is a matter of common knowledge that spring wheat should be seeded early. Wheat seeded the latter part of May is often not worth cutting, while wheat seeded in the same field early in April produces a satisfactory crop. In actual practice it may be essential

B 7, Plowed in spring.....

27.8 bus.

B 8, Plowed in fall.....

24.9 bus.

Fig. 6. Spring plowed land produced an average of 2.9 bushels more wheat than fall plowed land for an average of 14 years when both plots were seeded at the same time in the spring.

to plow as much of the land to be devoted to spring wheat as possible the fall before, in order to complete spring planting at the proper time.

DEPTH OF SPRING PLOWING FOR SPRING WHEAT

The depth of spring plowing has not been an important factor affecting the yield of spring wheat when grown continuously on the same land. As shown in Table V, six plots were spring plowed at

Table V. Effect of Depth of Spring Plowing on Yield of Spring Wheat

(Acre yield in bushels.)

YEAR	B 7 Plowed 7 ins. deep annually	B 9 Plowed 5 ins. deep even yrs., 5 ins. deep odd yrs.	B 10 Plowed 5 ins. deep even yrs., 8 ins. deep odd yrs.	B 12 Plowed 4 ins. deep annually	B 13 Plowed 6 ins. deep annually	B 14 Plowed 8 ins. deep annually
1899	25.6	29.7	29.7	35.7	34.1	32.2
1900	14.5	9.1	7.7	15.9	11.6	15.1
1901	34.9	36.9	33.6	34.7	34.7	33.8
1902	36.9	35.8	34.7	36.3	39.1	36.9
1903	37.4	35.7	35.7	37.3	38.5	33.0
1904	17.0	21.4	17.0	22.5	21.4	22.0
1906	20.9	23.6	23.6	22.5	28.6	19.8
1907	37.9	40.1	41.2	40.1	42.9	36.3
1908	29.1	12.1	26.2	22.5	26.9	25.3
1909	45.4	41.2	45.1	42.6	39.0	38.2
1910	28.3	54.1	31.3	30.2	34.4	31.3
1911	17.6	16.5	9.9	8.8	8.2	15.4
1912	36.8	31.1	40.1	34.7	39.0	39.6
1913	22.0	23.1	25.3	24.7	23.6	24.7
1914	17.3	14.9	15.9	16.5	16.5	21.2
1915	14.6	12.1	13.1	13.1	11.3	13.3
1916	41.8	48.1	48.7	47.6	39.9	48.9
1917	25.6	25.3	29.1	33.5	29.1	28.4
1918	19.5	19.5	22.3	22.3	27.2	22.5
1919	31.9	32.7	30.8	34.1	35.7	35.7
Average	27.8	28.1	28.0	28.8	29.1	28.7

various depths and seeded to spring wheat annually. The plot plowed seven inches deep produced an average yield of 27.8 bushels per acre, while the one plowed six inches deep produced an average yield of 29.1 bushels. The average yield of the other plots came

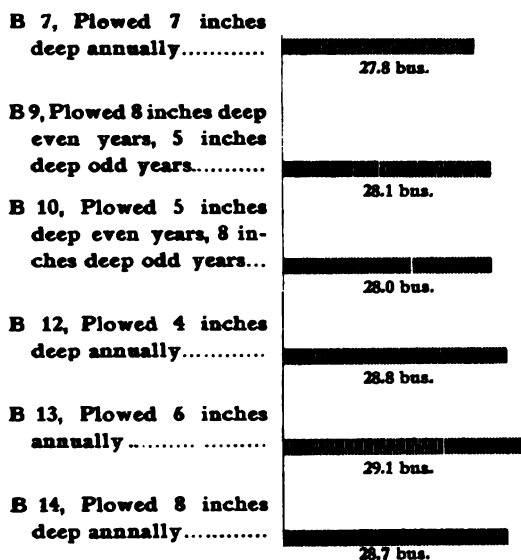


Fig. 7. How deep to plow. The results of 20 years show that the yield of spring wheat was not materially changed by varying the depth of plowing.

between these extremes. A difference in yield of only 1.3 bushels per acre was therefore obtained for the different depths of plowing. Data have been kept on these plots for twenty years and the results given are the average for the entire period.

Shallow plowing costs less than deep plowing and is more economical unless some definite advantage can be attributed to deep plowing. The results obtained for depth of plowing would no doubt vary under different conditions, and those given are for conditions at Pullman, Washington, when spring wheat was seeded on spring plowing.



Fig. 8. The Spillman plots at harvest time.

SUMMARY

1. The experiments reported in this bulletin were conducted on Field Six which occupies the lower portion of a south slope. The soil is a typical Palouse silt loam.
2. Manure applied in the spring each year before plowing at the rate of 10 tons per acre increased the average annual yield of spring wheat 2.2 bushels per acre.
3. Manure applied in the fall each year before plowing at the rate of 10 tons per acre increased the average annual yield of winter wheat 14.2 bushels per acre.
4. The use of manure for winter wheat produced an average annual increase of 12 bushels more than the use of manure for spring wheat.
5. There was a variation in acre yield of 1.3 bushels for winter wheat grown alternating with summer fallow when manure was applied before plowing, as a top dressing after plowing, and as a top dressing after seeding.
6. Early plowed well tilled summer fallow produced 11.8 bushels per acre more than summer fallow which was plowed late and left untilled.

7. The average yields during the second ten years of the period were greater than during the first ten years for six of the seven plots when wheat was grown in rotation.

8. Continuous cropping of both spring and winter wheat materially decreased the average yield during the second ten year period.

9. Spring plowing for spring wheat produced an average of 2.9 bushels more per acre than fall plowing for spring wheat. Usually it is desirable, however, to plow as much land in the fall as possible in order to insure early spring seeding.

10. The depth of spring plowing has but little influence on the yield of spring wheat.

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**STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON**

DIVISION OF ANIMAL HUSBANDRY

**Studies on Digestibility of Sunflower
Silage Fed to Sheep**

By

J. SOTOLA

**Bulletin No. 161
(Technical Paper)
January 1921**

**All Bulletins of this Station are sent free to citizens of the State on
application to the Director**

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**In co-operation with the United States Department of Agriculture.

***In co-operation with Chelan County.

Studies on Digestibility of Sunflower Silage Fed to Sheep

BY
J. SOTOLA *

(Submitted for Publication December 11th 1920)

In sections of Washington where corn silage cannot be produced successfully, because of climatic conditions, sunflower silage promises to become a feed of considerable importance. The larger yield per acre, adaptability to ensiling, as well as palatability of the silage, are some factors that point to an increased production of this roughage, even though it is lower in feeding value than corn silage. Studies of the methods of utilizing this new feed, therefore are of interest.

The work here reported was confined to a study of digestibility of sunflower silage when fed to wether lambs.

Animals Used.—Two grade wether lambs were used. They were fed in closed stalls in a quiet place, and were gradually accustomed to an exclusive sunflower silage ration, and kept on it for a sufficient length of time, (about 14 days) to empty their digestive tract of residues of other feeds before the trial proper began. Lamb I. weighed 82 lbs. and Lamb II, 71 lbs.

Method.—Sunflower silage lends itself to a direct method of investigation, as it may be used as the sole source of feed of lambs for a considerable period of time without any noticeable impairment of the health of the experimental animals.

The common method of determining the digestibility of a new feed involves actual digestion experiments of several days duration (10 days in this instance), during which the quantity and composition of feed consumed and feces excreted are carefully determined. In this way the quantity of protein, fats, carbohydrates, crude fiber,

*It is with pleasure that the writer makes acknowledgement to Professor H. Hackedorn for helpful suggestions and to Mr. Richard Hanna for care of experimental animals.

etc. which are eaten and excreted are calculated. The percentages of nutrients which have disappeared as the material passes through the digestive tract are called the coefficients of digestibility. It is assumed that all the material in the feces is feed residue, since materials from other sources form but a small portion of the feces of a ruminant. About four grams nitrogen is excreted for each 100 grams dry matter digested.

The difference between the amounts of nutrients in the feed fed and those in the feed refused is the actual amount of nutrients consumed. The calculation of coefficients then involves a determination of nutrients (1) consumed, (2) excreted, and (3) digested. The last is obtained by subtracting the second from the first. The coefficient of apparent digestibility for any nutrient is then calculated by dividing the quantity digested by the quantity consumed and multiplying the quotient by one hundred.

The plan of the trials was similar to that outlined in Bulletin 157 of this Station, with a few modifications. The feces were collected in rubber bags held in position by a suitable harness (see Figures I and II). The bags were emptied twice daily and the feces



Figure No. 1

The photograph of Lamb I was taken the last day of the digestion trial. This lamb was dropped in the spring of 1919, and weighed 82 lbs. at the time the picture was taken.



Figure II.
Lamb II with digestion harness in position

sampled, aliquot samples being weighed out for moisture determinations and chemical analyses. The urine was not collected since all solids in that excretion are considered as having been digested.

Silage fluctuates in moisture content and composition at various depths of the silo; the moisture varies with the time of exposure to air; silage spoils and molds if exposed to air for any considerable length of time. For these reasons all silage fed on any particular day was obtained fresh from the silo, thoroughly mixed and samples taken for analysis, and one days feed for each lamb weighed into air tight receptacles each morning. The amount fed each day was constant after being so adjusted as to reduce the refuse to the minimum. The refuse silage was collected and retained in air tight jars until the end of the trial when a sample was taken for chemical analysis.

Results.—Table I shows the average analysis of the silage fed each day. The analyses were made by the writer according to methods outlined by the Association of Official Agricultural Chemists. This table is of special interest as it presents the average of ten duplicate analyses of sunflower silage taken during the digestion

trial; and it is the basis for calculating digestible nutrients in sunflower silage in this investigation.

Table I.
Average percentage composition of fresh sunflower silage.

Average 10 days	Per cent. water	Per cent. D. M.	Per cent. protein N. x 6.25	Per cent. crude fat	Per cent. crude fibre	Per cent. fat	Per cent. crude ash
10 day av.	77.88	22.12	1.72	1.76	6.52	9.96	2.16

Table II shows the average daily feed fed, feces excreted and dry matter in each for lamb I and II during the 10 days digestion trail.

Table II.
Dry matter in feed and feces.

	Silage fed daily grams	Per cent. moisture in silage	Dry matter fed grams	Av. weight feces excret'd daily grams	Per cent. moisture in feces	Dry matter excreted grams
Lamb I	2700	77.88	597.24	310.91	52.08	148.99
Lamb II	2700	77.88	597.24	582.27	51.16	284.38

It should be noted that Lamb I refused 10,168.0 grams of feed in 10 days and Lamb II 1876.0 grams of feed during the same period.

Table III.
Quantity of feed constituents in silage fed and refused per day.

Average 10 days	Dry matter grams	Crude protein (N. x 6.25) grams	Crude fat grams	Crude fibre, grams	N. free ext., grams	Crude ash grams
Silage fed Lamb I and II	597.24	46.41	47.46	176.09	268.83	58.45
Refuse silage	242.00	18.51	12.40	77.18	109.81	24.10
Lamb I Refuse silage	52.81	2.33	.99	26.08	20.00	3.41
Lamb II						

Table IV gives the average daily composition of fresh feces of Lamb I and II. Even though Sheep II excreted double the amount of feces each day that Sheep I did, the composition of feces of the two sheep was very similar

Table IV.
Percentage composition of the feces.

Average 10 days	Dry matter grams	Crude protein grams	Crude fat, grams	Crude fibre, grams	Nitrogen free ext., grams	Crude ash, grams
Lamb I	47.92	3.49	1.57	17.82	19.70	5.35
Lamb II	48.74	3.62	1.82	16.47	19.35	5.68

Neither sheep showed any external symptoms of digestive disorders throughout the entire experiment.

Table V.
Quantity of feed constituents in feces per day.

Average 10 days	Dry matter grams	Crude pro- tein, grams	Crude fat, grams	Crude fibre grams	Nitrogen free ext., grams	Crude ash, grams
Lamb I	148.99	10.80	4.85	54.50	60.41	16.38
Lamb II	284.38	19.67	9.92	102.21	113.32	28.80

Tables VI and VII summarize for the ten day feeding period the following data for Lamb I and II respectively:—nutrients in feed fed, in feed refused, in feed consumed, in the feces and those digested. The last line gives the coefficients of digestibility of each of the nutrients in sunflower silage, as determined in this investigation.

Table VI.

Summary 10 day digestion trial. Lamb I.

	GRAMS	Dry Matter Grams	Protein Grams	Fat Grams	Crude Fibre Grams	Nitrogen Free Extract Grams	Ash Grams	Organic Mat- ter Grams
Sunflower silage fed	27000.0	5972.4	464.1	474.6	1760.9	2688.3	584.5	5387.9
Sunflower silage refused	10168.0	2420.0	185.1	124.0	771.8	1098.1	241.0	2179.0
Total silage consumed	16832.0	3552.4	279.0	350.6	989.1	1590.2	343.5	3208.9
Peces	3109.1	1489.9	108.0	48.5	545.0	604.1	163.8	1326.1
Total Digested		2062.5	171.0	302.1	444.1	986.1	179.7	1882.8
Percent digestibility		58.1	61.3	86.3	44.9	62.0	52.3	58.7

Table VII.

Summary of 10 day digestion trial. Lamb II.

	Grams	Dry matter grams	Protein grams	Fat grams	Crude Fibre grams	Nitrogen free extract grams	Ash grams	Organic mat- ter, grams
Sunflower silage fed	27000.0	5972.4	464.1	474.6	1760.9	2688.3	584.5	5387.9
Sunflower silage refused	1876.0	528.1	23.2	9.9	260.8	200.0	34.1	494.0
Total silage consumed	25124.0	5444.3	440.0	464.7	1500.1	2488.3	550.4	4893.9
Peces	5822.1	2843.8	196.7	99.2	1022.1	1133.2	288.0	2555.8
Total digested		2600.5	244.1	365.5	478.0	1355.1	262.4	2338.1
Percent digestibility		47.7	55.3	78.6	31.9	54.5	47.7	47.8

The first part of table VIII gives for comparison the averages of all analyses made at this station of corn and sunflower silages. The sunflower silage was lower in nitrogen free extract, but was higher in crude fibre than corn silage. The second part of table VIII compares the coefficients. These, for sunflower silage, are averages for the two sheep. The last part of the table affords a comparison of the two roughages on the basis of digestible feed constituents which they contain. While further work will be conducted, it is felt that the results thus far secured are of sufficient interest to be reported at this time.

The results given in this work are based upon two careful digestion trials, but with only two wether lambs. One lamb consumed about 54% more dry matter than the other. The lamb consuming the smaller amount of feed showed slightly higher coefficients of digestibility. However, the variation does not exceed those which might be attributed to individual differences. Lamb I, lost $\frac{1}{2}$ lbs. and lamb II, lost $1\frac{1}{2}$ lbs. during trial. (Weights based on three consecutive daily weights at the beginning and end of the trial.)

Aside from the fact that a small number of animals was used, this work has further limitations since silage is very seldom fed alone. No indication is obtained as to the digestibility of the feed when fed with alfalfa hay or other feeds. Previous experiments by various investigators point out strikingly that feeds fed together in a ration exert marked influence upon the digestibility of each other.

Table VIII.
Comparison of composition, coefficients of digestibility and digestible
nutrients of corn and sunflower silage.

	Dry Matter	Crude Protein N x 6.25	Crude Fat	Crude Fibre	N. F. Ext.	Crude Ash	Total dige. nut. XX.	Nutrient Ratio 1:
Chemical analyses of silage percent corn	28.40	1.99	.91	5.94	17.58	1.98		
sunflower	22.12	1.72	1.76	6.52	9.96	2.16		
Coefficients of digestibility corn *		51.0	82.0	65.0	71.0			
sunflower		58.3	82.4	38.4	58.2			
Silage digestible nutrients 100 lb. corn		1.01	.75	3.86	12.48		19.04	17.80
100 lb. sunflower		1.00	1.45	2.50	5.79		12.55	11.55

*Taken from Henry, W. A., and Morrison, F. B., Feeds and Feeding. XX Sum of crude protein, fat times 2.25, crude fibre and nitrogen free extract.

Summary

1. Sunflower silage is a palatable, succulent roughage adapted to feeding lambs.

2. In this investigation, sunflower silage made by ensiling fairly matured sunflowers had a nutritive ratio of 1 to 11.5 when fed to two lambs as compared to an average for all classes of live stock, of 1 to 17.9 for corn silage.

3. In 100 lbs. of this sunflower silage there were 12.55 lbs. of digestible nutrients, as compared to 19.04 lbs. digestible matter for each 100 lbs. of corn silage.

4. When comparing the two silages as to the content of digestible nutrients, sunflower silage in this test, had only 66 % of the value of corn silage.

5. The crude protein of sunflower silage in this test was 12.4 percent more digestible than the crude protein of corn silage; however the crude fiber of sunflower silage was about 40 percent less digestible. The nitrogen free extract was 18 percent less digestible in sunflower silage than in corn silage.



Figure illustrating the luxuriant growth of sunflowers at Pullman, Washington. Sunflowers yielded 12.0 tons of green material per acre where corn yielded only 6.7 tons in 1919. In 1920 sunflowers yielded 11.2 tons green matter per acre where corn yielded 5.3.



Figure illustrating the size of corn grown in the Palouse country for ensiling. Although the plants do not attain much height the proportion of grain to fodder is fairly high.

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STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISION OF FARM CROPS

SUNFLOWER PRODUCTION
FOR SILAGE

by

E. G. SCHAFER and R. O. WESTLEY

BULLETIN No. 162

April, 1921

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Sunflower Production for Silage

By

E. G. Schafer and Roy O. Westley

Introduction

It seems likely that the production of sunflowers for silage will meet one of the forage crop needs for certain districts of Washington. The discussion contained in this bulletin is intended to supply information concerning their culture and probable value. It is based largely upon data obtained and observations made at the Agricultural Experiment Station, Pullman, Washington, during the two years the crop was under investigation. Additional information has been secured from other experiment stations, and from reports furnished by county agriculturists who have made studies of sunflowers in various counties of this state. It is not expected that these results will be accepted as final conclusions, but it is hoped that they may be of value to persons who contemplate growing the crop.

Conditions Favorable for Sunflowers

Sunflowers grow well over a wide range of soil and climatic conditions. Soils ranging from clay and silt loams to those containing a large amount of sand are suitable for their culture. A high state of fertility is not essential, but a much larger yield will be produced on good soils than on poor ones. The largest production of the crop occurs where there is a long growing season and continued warm weather. Conditions favorable for corn are usually favorable for sunflowers. However, sunflowers are not easily affected by cold and do not suffer from light frosts after they are up in the spring. Areas which are not well suited for corn production on account of cold weather or insufficient moisture frequently produce a profitable crop of sunflowers, as is shown by the marked success with which the crop has been grown in many parts of this and other states.

Preparing the Land for Planting

Lands intended for sunflowers should usually be plowed in the fall and left without further tillage until spring. As soon as field conditions are favorable for tillage operations in the spring, the land should be harrowed, or if it has become firmly packed it should be disked to prevent the surface from crusting. If not plowed in the fall it should be plowed in the early spring and harrowed immediately. The ground should be given sufficient early tillage to form a mellow seed bed, and harrowed just before planting.

Planting the Crop

Sunflowers should be planted early in the spring, since it is desirable to have a long growing season. In districts where corn is grown usually they may be planted two or three weeks before it is safe to plant corn.

Seeding may be done with the ordinary grain drill by stopping up some of the holes so that those left seeding may place the rows at the desired distance. The space left between rows should be great enough to permit cultivation and the plants should be far enough apart in the rows to insure proper development. Where corn is planted three kernels to the hill three and one-half feet apart, a satisfactory distance for sunflowers should be 12 to 18 inches, in rows three and one-half feet apart. Approximately five to eight pounds, depending upon the size of seed, are required to plant an acre with rows three and one-half feet apart and the seeds spaced three inches apart in the row. When seeded at this rate the plants will have to be thinned after they are up. When it has been determined that a high per cent of field germination can be secured, it is possible that a less quantity of seed may be used, and the necessity of thinning avoided. The actual amount of seed required and the final spacing of plants in the row varies with the soil and climatic conditions.

The seed should be planted from one and one-half to three inches deep. The depth should be somewhat greater in a sandy soil or one that dries out readily than in a clay soil, and late seeding should be at a greater depth than early seeding.



Fig. 1. The ability of the sunflower to produce a heavy yield of green material suitable for silage makes it a valuable crop.

Cultivation

Cultivation should be practiced to destroy weeds and provide favorable conditions for the growing plant. Weeds should not be allowed to grow, since they use moisture and plant food needed by the crop. They are most easily destroyed at the time of germination, and cultivation should be frequent enough to keep the field free from them.

Cultivation helps to insure favorable growing conditions by putting the soil in a better state of tilth. It should not be deep enough to interfere seriously with the roots, yet deep enough to keep the soil from becoming hard and crusted at or near the surface.

Yield of Crop at This Station

The vigorous nature of sunflowers usually insures a heavy yielding crop. The woody character of the mature plants makes them of little value as feed for live stock when cured as fodder. This difficulty is overcome to a large extent when they are properly cut and stored in the silo. The crop utilized in this form deserves special consideration in districts where it produces larger yields than other crops commonly grown for silage.

When grown for silage sunflowers produced approximately twice the yield of corn for an average of two years on the experimental fields at Pullman, Washington.

Table I.—Acre Yield of Sunflower and Corn Silage

Crop	Acre yield in tons		
	1919	1920	Average
Sunflowers	12.00	11.19	11.59
Corn	6.68	5.27	5.97

The table gives the total green weight per acre for both sunflowers and corn for 1919 and 1920, and the average for the two years. In 1919 the plots were one-half acre in size and in 1920 one-fourth acre. The experiment was conducted in duplicate both years and each yield given is the average for two plots. In 1920 the sunflowers contained an average of

79.0 per cent of moisture and the corn contained 70.37 per cent at the time the crops were harvested and put into the silo. The Mammoth Russian variety of sunflowers was used, and the corn was Windus White Dent.



Fig. 2. The data giving the yield of sunflowers and corn in the accompanying table were obtained from plots located side by side where the growing conditions were made as nearly uniform as possible.

In 1919 the sunflowers were planted on May 3, and on May 12 in 1920, in rows spaced three and one-half feet apart and thinned to an average of 15 inches in the row. The corn was planted May 20 in 1919 and May 21 in 1920, three kernels in a hill spaced three and one-half feet apart each way. Both crops were harvested when they appeared to be at the proper stage of maturity for silage. The seed of the sunflowers producing the larger heads was beginning to harden, while the corn was well dented and passing out of the hard dough stage.

In 1920 a field of 3.7 acres on the college farm at Pullman produced 60.5 tons, or an average of 16.4 tons to the acre. An adjacent field of 4.3 acres of corn produced an average of 6.8 tons per acre the same year.

The production of seed received special attention during 1920 only. Forty-one different selections grown on small plots produced an average yield of 1556 pounds of seed per acre. Each selection represented the seed of an individual head, however, all selections were of the Mammoth Russian variety. The rows were three feet apart and the plants 15 inches apart in the row.

Yields at Various Places

Prior to 1900 the crop was shown to be a heavy yielder at some of the agricultural experiment stations, but its use as a silage crop was given little if any consideration at that time.

In 1917, 23 tons of sunflower silage as compared with 14 tons of corn silage was reported by the Nevada Experiment Station (1) when grown under irrigation.

The Montana Experiment Station (2) reports a sunflower yield of 44.1 tons of green forage per acre for an average of the years 1917 and 1918, when seeded at the rate of five pounds per acre in rows 36 inches apart. This was the highest yield obtained with rows spaced at various intervals, and the crop was grown under irrigation.

An acre yield of 34.6 tons of sunflowers and 14 tons of corn, grown under irrigation, is reported from the demonstration farm at Strathmore, Canada, (3) for the year 1919.

Data from the Michigan Experiment Station (4) of yields on their Upper Peninsula Station at Chatham, show sunflowers varying from 11.3 to 20.4 tons per acre in a date of seeding test.

At the Umatilla Reclamation Project Experiment Farm (5), located in northeastern Oregon, 51 varieties of corn and one variety of sunflowers were grown for silage. The crops were grown under irrigation and the experiment was conducted during 1918 and 1919. The acre yield of the sunflowers was 28.4 tons, while the leading variety of corn produced only 10.8 tons.

A report by letter from the Colorado Experiment Station emphasized the value of sunflowers where corn can not be successfully grown. It stated that yields of from 14 to 18 tons

of sunflowers were obtained at altitudes where corn can not profitably be produced at all. Yields of over 30 tons per acre were secured under irrigation on the Station farm.

The Idaho Experiment Station has reported a yield of 19 tons per acre for a field of four acres in 1920.

Reports of yields of sunflowers for silage at various experiment stations show them to be a profitable crop, particularly where corn does not do well.

Sunflowers in Washington are rapidly gaining favor and proving their value. Reports from 16 counties in this state show that they have been grown with varying degrees of success. Yields have been produced ranging from five tons in the drier sections to 42 tons under more favorable conditions. These reports have come from typical localities in the northern counties, the Palouse country, the dry belt, the irrigated sections and the west side. In most cases a comparison was made with corn and it was found that their yield greatly exceeded that of corn.

Effect on Following Crop

It was observed on the experimental fields in 1919 and 1920 that the outside rows of the sunflower plots which were next to the corn, made a more vigorous growth than those rows near the center of the plots. The corn on the rows next to the sunflower plots, however, was smaller in size than that in the center of the plots. Sunflowers, therefore, not only produce a heavier acre yield than corn, as shown in Table I, but they seemed able to obtain a greater portion of the plant food and soil moisture when grown side by side.

The value of the cultivated crop is in part measured by the following crop yield. In order to determine this, and since cultivated land is commonly used for wheat the following year, the plots which were in corn and sunflowers in 1919 were seeded to Bluestem wheat in 1920. The average yield produced on the corn plots was 33.78 bushels per acre, while that produced on the sunflower land was 28.36 bushels. While these data indicate that land used for sunflowers is somewhat less suitable for immediate wheat production than corn land, they should not be taken as final conclusions. The degree to which

they apply will depend largely upon the amount of moisture present in the soil, which may vary in different localities and with different seasons.



Fig. 3. Sunflowers are utilized to the best advantage when put in the silo.

Filling the Silo

Sunflower silage of a satisfactory quality has been produced by harvesting the crop when the seeds of the best developed heads are fully formed and commencing to harden. It is likely that the proper time will be determined with greater certainty after additional experience is gained in the use of the crop.

The methods commonly used for harvesting and putting corn in the silo may be employed for sunflowers, except in case the stalks are too large for corn harvesting machinery to handle them successfully. Under such conditions the crop may be cut by hand with a corn knife. In either case they should be hauled to the cutter immediately, cut into short pieces and stored in the silo. Particular care should be given to packing the material firmly, for it is essential to the preservation of

silage that the air be excluded. On account of the high moisture content of sunflowers, they seldom require the addition of water to aid in packing.

Comparative Value of Corn and Sunflowers When Grown for Silage

The early production of sunflowers in the United States was primarily for their seed and only in recent years has their use for forage been given special consideration. The value of a crop for forage purposes depends principally on five factors; namely, yield per acre, cost of production, ease of curing and storing, palatability, and nutritive value.

In many districts sunflowers produce a greater acre yield than corn, the crop with which they are generally compared, as is shown in Table I and various experiments cited in this bulletin.

The cultural methods employed in the production of sunflowers are essentially the same as those for corn; therefore the cost of producing the two crops is practically identical.

Since sunflowers for feed are utilized to the best advantage when stored in a silo, and since a large tonnage may be handled in such a small space, the curing and storing of the crop in this manner is comparatively simple.

In a preliminary feeding experiment with dairy cattle at this Station (6) it was concluded that "sunflower silage was considerably less palatable than the corn silage." It was further stated, however, that "the corn silage used in this trial was of especially good quality, being quite rich in grain. The sunflower silage would probably be considered as of medium quality."

The Montana Experiment Station (2) summarizes its results in the following manner: "Little difficulty has been experienced in getting stock to eat sunflower silage. In some cases a few days have been required to get them to eat it readily. It is palatable to cattle, sheep and swine."

The evidence obtained from these experiments together with that of growers indicates that sunflower silage is not as pal-

atable as corn silage. Dairy cows eat it less greedily and consume a smaller quantity.

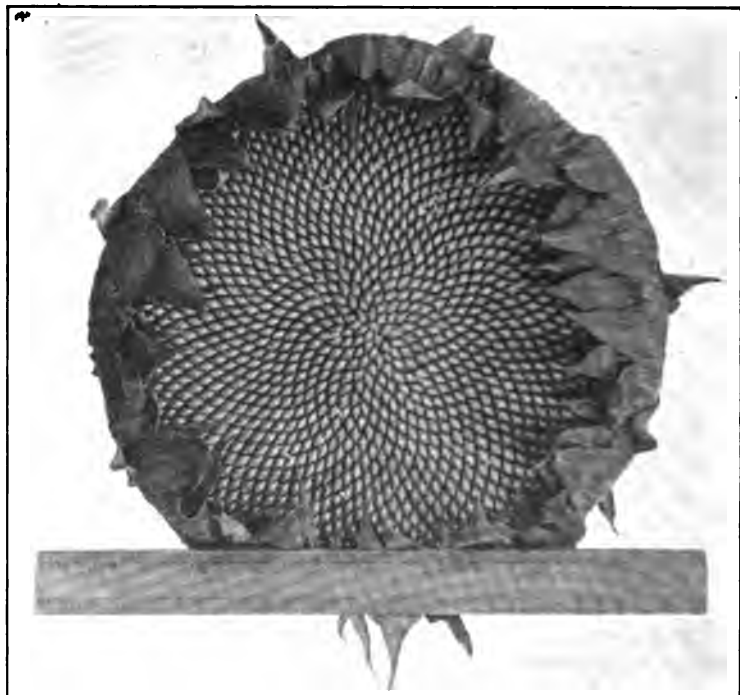


Fig. 4. The seed of a well developed head increases the feeding value of the silage.

The nutritive value of sunflowers is somewhat less than that of corn. In the preliminary experiments, comparing sunflower and corn silage, as feeds for dairy cows at this station, referred to above, it was found that "sunflower silage was approximately 92 per cent as valuable as corn silage." The Montana Experiment Station (2) reports the results of a test which indicated that sunflowers and corn were of equal feeding value when five per cent of the sunflowers were in bloom and the corn was in the silk stage. Both crops were run through a feed cutter and cut into one-inch lengths.

The following table gives the digestible nutrients in 100 pounds and nutritive ratio of sunflower silage as determined with sheep at this Station (7), and of corn silage, which were obtained from analyses made at this station, to which were applied the co-efficients of digestibility as reported by Henry and Morrison (8).

Table II.—Digestible Nutrients in Sunflower and Corn Silage

Crop	Total dry matter in 100 pounds	Digestible nutrients in 100 lbs.				Nutritive ratio
		Crude protein	Carbohy-drates	Crude fat	Total Inc. fat x 2.25	
Sunflowers	22.12	1.00	8.29	1.45	12.55	1:11.55
Corn	28.40	1.01	16.34	.75	19.04	1:17.80

The approximate acre value at this Station in terms of digestible nutrients may be ascertained by using the values given for silage in the above table and the acre yields given in Table I.

Table III.—Digestible Nutrients of Sunflowers and Corn

Crop	Acre yield of dry matter. in pounds	Digestible nutrients from one acre in lbs.			
		Crude protein	Carbohy-drates	Crude fat	Total inc. fat x 2.25
Sunflowers	4867.80	220.06	1824.32	319.09	2762.33
Corn	3537.82	125.82	2035.49	93.43	2371.53

In accepting these results it should be understood that the acre yield in dry matter is based on weights at the time of harvesting and the digestible nutrients given are those of silage. The actual weight of digestible nutrients will depend somewhat upon the loss of dry matter and changes in digestibility that occur between the time the crop is harvested and the formation of silage.

Suggestions for Feeding Sunflower Silage

The sunflower silage produced at this Station has been fed to dairy cattle, beef cattle and sheep. It has been used in pre-

liminary feeding experiments and as part of a general ration. From the results obtained in this manner the following suggestions concerning its use in feeding dairy cows have been made by the Dairy Division, and those concerning its use in feeding beef cattle and sheep have been made by the Division of Animal Husbandry.

This succulent feed has proved to be fairly satisfactory and can be substituted for corn silage in rations for dairy cattle, beef cattle and sheep. It should be fed with some dry roughage.

Sunflower Silage for Dairy Cattle

The amount of sunflower silage fed to each cow should not exceed 25 to 30 pounds daily when it is fed in connection with alfalfa or other legume hay. Cows receiving these feeds should be allowed all the hay they will clean up. In addition to the roughage the following grain mixtures are recommended:

For cows giving milk testing 3.5 to 4.0 per cent fat:

Mixture 1.

Rolled barley or ground corn	100 pounds
Bran or mill run	300 pounds
Linseed oilmeal, soybean oilmeal, or cotton- seed oilmeal	50 pounds
Total	450 pounds

Mixture 2.

Bran or mill run	200 pounds
Ground oats	200 pounds
Linseed oilmeal, soybean oilmeal, or cotton- seed oilmeal	50 pounds
Total	450 pounds

Mixture 3.

Rolled barley or ground corn	100 pounds
Ground oats	100 pounds
Linseed oilmeal, soybean oilmeal, or cotton- seed oilmeal	100 pounds
Total	300 pounds

For cows giving milk testing above 4 per cent fat:

Mixture 4.

Rolled barley or ground corn	100 pounds
Bran or mill run	300 pounds
Linseed oilmeal, soybean oilmeal, or cotton- seed oilmeal	25 pounds
Total	425 pounds

Mixture 5.

Bran or mill run	100 pounds
Ground oats	200 pounds
Linseed oilmeal, soybean oilmeal, or cotton- seed oilmeal	30 pounds
Total	330 pounds

Mixture 6.

Rolled barley or ground corn	100 pounds
Ground oats	200 pounds
Linseed oilmeal, soybean oilmeal, or cotton- seed oilmeal	110 pounds
Total	410 pounds

Grain should not be fed to cows producing less than 15 pounds of milk daily. Mixtures 1, 2 and 6 should be fed at the rate of one pound per day for each two pounds of milk produced in excess of 15 pounds. Mixture 3 should be fed at the rate of one pound for every two and one-fourth pounds, and mixtures 4 and 5 at the rate of one pound for every one and one-half pounds of milk produced daily in excess of 15 pounds.

Sunflower Silage for Sheep

A lot of pure bred lambs made an average daily gain of 0.225 pounds each when fed a daily ration of one pound barley, one-half pound cull beans, four-fifths pound of pea straw and two and one-half pounds of sunflower silage. Thrifty breeding ewes two to four years old, which were fed a daily ration of two pounds of alfalfa hay and three pounds of sunflower silage per head, were maintained in good breeding condition for 60 days.

The following daily rations are recommended:

Ration 1, for young thrifty 100-pound breeding ewes:

Alfalfa hay	2 to 3 pounds
Sunflower silage	3 pounds

OR

Cottonseed oilmeal	$\frac{1}{4}$ pound
Pea straw	2 pounds
Sunflower silage	3 pounds

Ration 2, for thin 60-pound feeder lambs which are to be fattened during a period of 70 to 100 days:

Rolled barley	$\frac{3}{4}$ to 1 pound
Cottonseed oilmeal	$\frac{1}{2}$ pound
Alfalfa hay	$\frac{3}{4}$ pound
Sunflower silage	2 pounds

Sunflower Silage for Beef Cattle

Beef cows can be satisfactorily wintered on a daily ration of 10 pounds of alfalfa hay, and 30 to 40 pounds of sunflower silage for each 1000 pounds of live weight. Two to three pounds of cottonseed oil meal and all the oat straw the cattle will eat can be substituted for the alfalfa hay. Two to three year old steers will make about one pound of gain daily for each 1000 pounds of live weight when fed a ration of 15 to 20 pounds of alfalfa hay and 40 pounds of sunflower silage per day. A gain of approximately two and one-half pounds a day can be made on good 1000-pound feeder steers two to three years old, with a daily ration of 13 pounds rolled barley, two pounds of cottonseed oil meal, eight pounds of alfalfa hay and 25 pounds of sunflower silage.

Diseases

Three sunflower diseases, rust, powdery mildew and wilt, under certain conditions may cause serious injury to the crop. The Plant Pathology Division of this Station has supplied the information given below regarding them.

Rust, *Puccinia helianthi*, occurs on the lower leaves first and from there spreads to the upper leaves if conditions are favorable for its development. The rust spots are yellow to brown early in the season, but later they turn black. When attacks are severe the leaves are killed and normal seed production prevented.

Powdery mildew, *Erysiphe cichoracearum*, is characterized by a white powdery growth over the surface of the leaves and leaf stalks. This coating becomes darker with age and scattered through it are small black specks, the fruiting bodies of the mildew fungus. Leaves which are badly infected die and a large proportion of the foliage, especially the lower leaves, may be lost. Seed production on badly affected plants is reduced.

Wilt, *Sclerotinia* sp. The lower portion of the stem is attacked during the spring or early summer, causing the tissue of the affected parts to break down and rot. The fibrovascular

bundles of the stem are less affected than the surrounding softer tissue which condition gives the lesions a characteristic shredded appearance. If the plant is not killed immediately, the disease spreads upward through the stem and breaks out in the head. Hard black seed-like bodies of various shapes develop in the affected parts in the late summer or early fall. These bodies represent the fungus in its resting stage. The disease causes a wilting of the leaves, the lower ones often being killed immediately. Entire plants may fall over as a result of the weakening of the stems. The disease is favored by an abundance of moisture and greater damage occurs on bottom-land than up-land. Serious damage has been caused under such conditions in Western Washington. The casual organism is retained in the soil and sunflowers should not be planted on land which produced a crop infested with the disease the previous year.

REFERENCES

- (1) Nev. Bul. 91, 1918.
- (2) Mont. Bul. 131, 1919.
- (3) Canadian Pacific Railway, Silos and Silage Crops, 1920.
- (4) Mich. Quarterly Bulletin, Nov. 1920.
- (5) U. S. Dept. Agr. Cir. 110, 1920.
- (6) Wash. Bul. 158, 1920.
- (7) Wash. Bul. 161, 1921.
- (8) Feeds and Feeding.

Summary

1. Sunflowers for silage promise to be of greatest value in areas which will not produce corn satisfactorily on account of cold weather or insufficient moisture.

2. Sunflowers should be planted on a well prepared seed bed usually two or three weeks before it is safe to plant corn.

3. Sunflowers produced approximately twice the yield of corn when grown for silage on the experimental fields at Pullman.

4. The yields obtained at various state experiment stations and different counties in Washington show sunflowers to be a profitable crop, particularly in areas not well suited for corn.

5. The wheat yield following sunflowers was 16 per cent less than that following corn in 1920.

6. The dry matter and digestible nutrients are lower for sunflowers than for corn when equal weights are considered. The acre yield of digestible nutrients is greater, however, for sunflowers than for corn.

7. Sunflower silage is less palatable than corn silage but has proved to be fairly satisfactory and can be substituted for corn silage in rations for dairy cattle, beef cattle and sheep.

8. Under certain conditions the diseases rust, powdery mildew and wilt may cause serious injury to the crop.

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STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISION OF HORTICULTURE

STUDIES IN APPLE
POLLINATION

by

O. M. MORRIS

BULLETIN No. 163
MAY, 1921

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Studies in Apple Pollination

SELF-STERILITY OF VARIETIES*

In districts of home apple-orchards where many varieties are planted in each orchard and the entire planting contains only a few trees of each variety, no trouble has been experienced in securing a satisfactory set of fruit with normal blossom production. The peculiar market requirements of the Northwest have limited the commercial orchard plantings to a very few varieties. This has made the self-sterility of varieties of great importance. A few whole blocks of one variety have made prominent these characteristics by the failure of the plants to produce crops although blossoming abundantly.

Darwin (1) called attention to the fact that many varieties of cultivated plants are self-sterile. This gave rise to general discussion and some investigation. The foundation was laid for more comprehensive and exacting reports to be made. Among the first comprehensive reports published in the United States on sterility of fruits, was "The Pollination of the Pear Flower" by M. B. Waite, in the Division of Vegetable Pathology, Bulletin Number 5, 1894, U. S. D. A. Since then, studies in the pollination of apples, cherries, plums, grapes and various berry plants have been published. Questions of orchard pollination have been difficult to separate from those of the influence of environment. The influence of climate or weather and general well-being of the plant has been recognized as being important by practically all writers. The physi-

*The work reported in this bulletin has been in progress for several years. The field work in the study of self-sterility and inter-sterility of varieties was done mostly by Mr. W. J. Young, now of Geneva, Illinois, and Mr. F. W. Allen, Davis, California, while they were Assistant Horticulturists at this Station. The author wishes also at this time to express his appreciation of the assistance given by Messrs. J. C. Cave, Stockton, California, B. F. Brown, Walla Walla, Washington, and C. M. Lockwood, Opportunity, Washington.

cal difficulties in the way of pollination, such as rain at blossoming time, have been given attention by many investigators, and are generally conceded to be a very great handicap to the setting of fruit.

METHODS USED IN MAKING TESTS

Tests for self-sterility have been made upon all varieties available at the time the work was undertaken. M. B. Waite (2) found that blossoming twigs enclosed in paper, cheese-cloth, or mosquito-netting bags were not materially modified in their process of setting fruit. All three forms were used in this work but the paper bag was used for most of the work with very satisfactory results. The trees selected for the work were carefully watched and just before the blossoms began opening manila paper bags were placed over fruit spurs and short fruiting twigs and fastened with wire in such a way that insects could not enter. The bags were left in place throughout the blossoming period. After the size of the fruit on the remainder of the trees indicated that the blossoms which had failed to set fruit could be easily distinguished from those that had permanently set fruit, the bags were removed and counts made of the blossoms enclosed and of the fruits produced. From these figures the per cent of fruit set was calculated.

The trees used in this work were in normal orchard condition and in full vigor and fruit production. They produced what was estimated to be sixty to eighty per cent of a crop. The orchards were given clean tillage and did not suffer from drouth until late in the summer, if at all.

In order to make sure that pollination took place and that the failure to set fruit was not due to lack of pollination, certain paper bags were removed soon after the blossoms opened, and the blossoms were pollinated by hand. Waite (2) found that there is no difference in the fruit set when the flowers are self-pollinated, when pollinated with pollen from different flowers on the same tree, or when pollinated with pollen from

different trees of the same variety. Gowen (3) later reports results in exact agreement with those announced by Waite.

In this work the pollen of each individual blossom was applied to the pistils of the same flowers, or pollen from other covered blossoms of the same variety was used without discrimination. The blossoms were again covered and left until the final count of fruit was made. Hand-pollinated blossoms in the self-sterility tests gave the same results as blossoms that were kept continuously enclosed in the paper bags during the entire blossoming period. This seemed to indicate clearly that the failure to set fruit was not due to lack of pollination.

VARIATION IN DEGREE OF STERILITY OF VARIETIES

The varieties differ in the per cent of blossoms that set fruit in the various orchard conditions. There may also be a variation in the per cent of blossoms that set fruit in any one tree in the different years. Waite (2) says the state of nutrition of the tree and its general environment affect its ability to set fruit either with its own pollen or that of another tree. Gardner (4) says the ability of a variety of cherry to set fruit is not entirely dependent upon the kind of pollen available. Environmental factors are important. Hedrick (5) and Sandsten (6) draw the same conclusion in their work. Waugh (7) shows that the per cent of defective pistils in plum blossoms from different sections of the country varies greatly, and that this variation can not all be traced to cold winters. Yeager (8) found that the older spurs blossomed less frequently than younger spurs and that the blossoms on the old spurs more frequently failed to set fruit. The normal range for the variety in the commercial orchard is from five to fifty per cent. Nine to eleven per cent will ordinarily load the tree so that very heavy thinning is necessary. It is not uncommon for varieties of crab apples to set fifty to eighty per cent of the blossoms and some varieties that produce very small fruits set even as high as ninety-five per cent of the blossoms.

Table 1, Showing the Results of Tests in Sterility of Varieties of Apples

Variety	Number of blossoms covered	Per cent of blossoms that set fruit
1. Dutch Mignonne	635	0.63
2. Esopus (Spitzenburg)	476	6.93
3. Esopus (Spitzenburg)	410	0.73
4. Fallawater	624	5.3
5. Gravenstein	256	5.1
6. Grimes	2484	1.49
7. McIntosh	365	8.77
8. Oldenburg	253	11.46
9. Rhode Island Greening	714	1.7
10. Rome' Beauty	472	1.6
11. Wagener	311	.6
12. White Pearmain	492	.61
13. Winesap	654	2.61
14. Baldwin	534	1.48
15. Ben Davis	509	0.19
16. Delicious	530	0.0
17. Esopus (Spitzenburg)	507	0.0
18. Jonathan	504	0.0
19. King David	620	0.0
20. Lawver	506	0.0
21. Maiden Blush	508	0.0
22. Northern Spy	556	0.0
23. Rhode Island Greening	566	3.05
24. Rome Beauty	491	0.0
25. Tompkins King	503	0.0
26. Twenty Ounce	519	0.0
27. Wagener	1040	0.0
28. Wealthy	647	0.46
29. Winesap	442	0.0
30. Winter Banana	554	0.0
31. Yellow Newtown	503	0.19
32. Yellow Transparent	510	0.0

The results secured in the self-sterility tests are reported in Table 1. Varieties 1 to 13, inclusive, were growing in the Experiment Station orchard at Pullman. Varieties 14 to 32, inclusive, were growing in orchards in the Spokane Valley. The lack of uniformity of the result of the different tests is noticeable in this table and is illustrated in the per cent of fruit set in the different tests with the Esopus (Spitzenburg) variety. The degree of self-sterility varies in different localities and with different years in the same orchard.

Fallawater and Gravenstein are here shown to be partially self-fertile and Grimes and Yellow Newtown practically self-

sterile. Lewis and Vincent (9) report Fallawater and Gravenstein as self-sterile and Grimes and Yellow Newtown self-fertile in western Oregon. W. H. Wicks (10) in a three years' test in Arkansas found Ben Davis self-sterile two years and partially self-fertile one year, and Jonathan self-fertile one year and practically self-sterile two years. These results are in accord with those reported by other investigators.

The results quoted in the preceding paragraph were obtained under widely varying conditions of soil and weather. The records in each case were not sufficiently complete in all detail to furnish a basis for conclusions relative to the cause of the variation in the degree of sterility found. The data here presented indicate a general tendency of varieties to be self-sterile and that under different conditions a variety will often vary in the degree of self-sterility manifest.

The facts presented in Table 1 and the accompanying paragraphs clearly indicate that it is wise to assume that all varieties are partially self-sterile. No variety of apple should be planted in a large solid block but provision should be made for abundant opportunity for cross-pollination.

INFLUENCE OF INSECT POLLINATION

To determine the influence of insect pollination of blossoms on the setting of fruit and its possible relation to self-sterility, several tests were made by covering the trees with tents. Under one tent enclosing a Jonathan tree, a stand of bees was placed. Another Jonathan tree in the same orchard was covered with a tent, and so protected that it was practically impossible for bees or other insects to carry foreign pollen to any of the blossoms on the tree. Rome Beauty trees were subjected to the same test. The weather during the blossoming period was unfavorable but not destructive and only a light to medium crop was set. The per cent of blossoms that set fruit corroborated the self-sterility tests made on varieties by enclosing small branches in manila paper bags. No distinct advantage was secured by enclosing the stand of bees with the tree. The flowers were visited and well pollinated generally, but not at as frequent intervals as had been expected.

Whipple (11) states that winter injured fruit buds of the apple often open and many types of malformed flowers are produced and that fruits are developed from such flowers. Flowers in which both pistils and stamens were absent produced fruit. Such fruits were abnormal in form, seedless and usually coreless. In this case there is no reason to believe that the visitation of the bees was a factor of any influence in the setting of fruit. The attention of the public has several times been called to individual seedling trees that habitually produced seedless and more or less coreless fruits.

Table 2, A Comparison of the Seed Content of Jonathan Apples Produced by Trees That Were Covered With Cloth Tents During Blossoming Period and by Trees in the Open Orchard.

Treatment of tree	Size fruit	No. apples	Av. No. seeds	No. apples cont. but one seed	No. seed less apples
Covered with tent, all insects excluded	Very large	11	3.17	4	none
	large	16	1.92	6	none
	medium	23	1.54	13	1
	small	11	1.09	9	1
Covered with tent, inclosing a stand of bees	Very large	7	2.28	5	none
	large	23	1.34	18	none
	medium	15	1.06	11	2
	small	12	.83	10	2
Open orchard	Large	100	7.96	none	none
	medium	100	7.37	none	none
	small	100	5.68	none	none

Tables 2 and 3 record the yield of the trees, the seed content of the apples produced on the enclosed trees, and also the seed content of three hundred fruits gathered promiscuously from the neighboring trees of the same age in the same orchard. The trees of the same size standing adjacent to those covered, produced between 600 and 700 apples each. The very light set of fruit on the covered trees gave each fruit an opportunity to develop without contesting with others for food supply. The fruits that started to develop had to overcome only those processes of abscission which originate in the imperfectly fertilized blossoms. The number of fruits produced by the trees under test is too small to form a basis for

Table 8, A Comparison of the Seed Content of Rome Beauty Produced by Trees That Were Covered With Cloth Tents During the Blossoming Period and by Trees in the Open Orchard.

Treatment of tree	Size fruit	No. apples	Av. No. seeds	No. apples cont. but one seed	No. seedless apples
Covered with tent, all insects excluded	Large	10	7	none	none
	medium	24	3.58	3	none
	small	17	3.27	none	2
Covered with tent, inclosing a stand of bees	Large	7	.85	2	3
	medium	6	1.16	3	2
	small	5	1.2	2	2
Open orchard	Large	100	11.21	none	none
	medium	100	9.78	none	none
	small	100	9.62	none	none

definite conclusion, but seems to indicate a close relationship between sterility and seed content of fruit.

Over one thousand fruits of each variety of the normal orchard crop were examined for seed content and no seedless fruit was found. The fruits produced by the covered Jonathan tree had a very low seed content. Five per cent of these fruits contained no seed and sixty-four per cent contained only one seed each. The seedless fruits were normal in every characteristic except seed content.

There is no indication that insect pollination modified in any way the results secured in this experiment. The normal condition of the tree was not disturbed and the protection formed by the tents at blossoming time probably gave the tree an opportunity to avoid the elements of weather that thinned out the weaker fruits in the other trees in the orchard.

POLLEN PRODUCTION AND SELF-STERILITY

The amount of pollen produced by a variety is not an indication of the degree of self-sterility or self-fertility existing. Lewis and Vincent (9) give the pollen-bearing habits of 87 varieties of apples in terms of "abundant," "medium" and "shy" production. Table 4 is compiled from this report and shows that the total amount of pollen produced by a variety is not an indication of the degree of self-sterility or self-fer-

tility that may exist. The figures seem to indicate that abundant pollen production and self-sterility are opposing characters but the number of varieties considered is too small to warrant definite conclusions.

Table 4. Showing the Per Cent of Self-sterile and Partially and Entirely Self-fertile Varieties Classified According to Pollen Production

No. of varieties	Pollen production	Self sterile varieties	Partially and entirely self-fertile varieties
26	Abundant	80%	20%
44	Medium	68%	32%
17	Shy	52%	48%

DURATION OF POLLINATING PERIOD

Self-sterility does not seem to be due to the short duration of the life of the pollen or, fundamentally, to the lack of vitality of the pollen. Germination tests of the pollen from most of the commercial varieties were made by placing the pollen grains in sugar solutions. These tests failed to find any pollen that showed marked weakness or lack of viability. Sandsten (6) found that pollen four months old would show 38 per cent germination in a test made by placing the pollen in a sugar solution. In an orchard test, pollen was collected and stored for several days and then used with the result indicated in Table 5. These tests were sufficiently exhaustive to indicate that the period of viability of the pollen is not the primary limiting factor in creating self-sterility. Old or stored pollen does not uniformly give better results than fresh pollen, as the figures presented might be taken to indicate. The results here presented were selected from tests made for the purpose

Table 5. Showing the Per Cent of Apple Blossoms That Set Fruit When Pollinated With Pollen That Had Been Stored for Several Days

Treatment of pollen	Age in days	Per cent of blossoms that set fruit
Fresh pollen		18
Stored in dark	14	26
Stored in dark	21	24
Stored in sunlight	14	26
Stored in diffused light	21	45
Stored in desiccator	21	72

of determining whether the vitality of the pollen is a controlling cause of self-sterility of varieties of apples. The results secured with the fresh pollen were good and compared favorably with those secured in tests of cross-pollination work. The highest per cent of fruit set in the different trials with the stored pollen is given in the table.

The length of time during which the pistil is in the receptive state is not nearly so great as the period during which the pollen remains viable. The stigma is usually receptive within twelve hours after the blossom opens. If pollinated as soon as the blossoms open and fertilization takes place, the stigma often begins to shrink and wither within the succeeding twenty-four hours. These stages of development vary in length with the vigor of the tree, the variety, and the weather condition during the blossoming period. If fertilization does not take place, the stigma will often remain in a perfectly turgid and apparently receptive condition for three or four days or even longer under favorable conditions.

CROSS-POLLINATION

Inter-pollination of varieties requires the over-lapping of the blossoming dates and the more nearly the periods coincide in the cross-fertilizing varieties, the better is the opportunity for a satisfactory set of fruit. The blossoming periods of the varieties commonly grown in the Northwest overlap to a greater extent than is commonly supposed. Table 6 gives the blossoming data collected at the Experiment Station and in the Spokane, Wenatchee and Yakima Valleys. The blooming periods of varieties are nearly constant in their relation to each other. The difference that exists is slight and if the varieties are wisely selected, will seldom be great enough to prevent a good set of fruit.

The length of the blossoming period for apples is about nine days, but from the first blossom of the season to the last will often be fifteen to twenty days, depending upon the weather. Cool weather at blooming time will extend the period and warm weather will shorten it. Dry windy weather will also reduce the length of the period.

Table 6, Showing the Blossoming Dates at Pullman of the Most Common Varieties of Apples Grown in Washington

VARIETY	MAY																			
	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Aiken																				
Alexander																				
Arkansas (Mammoth Black Twig) ..																				
Arkansas Black																				
Autumn Strawberry	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Babbitt																				
Baldwin																				
Bottle Greening	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Baxter																				
Ben Davis																				
Black Ben Davis																				
Black Gilliflower																				
Blue Pearmain																				
Chenango																				
Colfax	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Delaware Red																				
Delicious																				
Dominie																				
Early Harvest	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Early Ripe																				
Early Pennock																				
Esopus (Spitzenburg)																				
Fallawater																				
Fameuse	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Gano																				
Gloria Mundi																				
Golden Sweet																				
Gravenstein	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Grimes Golden																				
Haas																				
Hibernal	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Table 6—(continued)

VARIETY

MAY

	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Hubbardston																				
Huntsman																				
Jefferis																				
Jonathan																				
King David																				
Limbirtwig																				
Longfield																				
Lowell																				
Malden Blush																				
Marshall																				
McAfee																				
McIntosh																				
McMahon																				
Missouri (Pippin)																				
Monmouth (Red Cheek Pippin)																				
Newtown Spitzenburg																				
Northern Spy																				
Oldenburg																				
Oliver																				
Paragon																				
Pewaukee																				
Rambo																				
Red Astrachan																				
Red June																				
Rhode Island Greening																				
Rome Beauty																				
Salome																				
Sops of Wine																				
Smith Elder																				
Stark																				
Stayman Winesap																				
Sweet Bough																				

Table 6—(continued)

VARIETY	7	8	9	10	11	12	13	14	15	16	MAY									
Sweet Russett			*	*	*	*	*	*	*	*	17	18	19	20	21	22	23	24	25	26
Tetofsky			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Tompkins King					*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Twenty Ounce						*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Vanderpool			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Wagener			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Walbridge			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Waxen	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Wealthy					*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Whitney			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
White Pearmain			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Wine		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Winesap			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Winter Banana					*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Yellow Newtown					*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Yellow Transparent				*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
York Imperial			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

INTER-FERTILITY OF VARIETIES

Lewis and Vincent (9) found that varieties that were self-fertile produced more fruit and larger fruit when cross-pollinated with an inter-fertile variety. This fruit also had a greater seed content than the selfed fruits. Fletcher (12) also noted marked increase in size in cross-pollinated fruits. Gowen (3) states that the number of good seeds in the crossed apples is greater than in those which are selfed.

Cross-pollination does not insure that the blossoms pollinated will be fertilized. Tests to determine which varieties were inter-fertile and inter-sterile were made by emasculating the blossoms to be used as the pistillate ones in the cross, before the blossoms opened. These blossoms were then covered with paper bags which were securely fastened to prevent ingress of insects or other pollen-carrying agents. Just before the trees were in full blossom the emasculated flowers were uncovered and unmixed pollen of the pollen-bearing varieties was applied to the pistils and the covering replaced. These blossoms were kept carefully protected until they had fallen or fruit had formed. These tests were made in the Experiment Station orchard and in the Spokane Valley. The data secured are arranged in order in Table 7.

Table 7, Showing the Per Cent of Fruit Set by Crosses

Blossom variety	Pollen variety	No. blossoms crossed	Per cent blossoms set fruit
Chenango	Gravenstein	93	3.25
Chenango	Jonathan	52	none
Chenango	McIntosh	148	22.97
Esopus (Spitzenburg)	Ben Davis	145	3.45
Esopus	Delicious	111	12.61
Esopus	Jonathan	112	11.61
Esopus	McIntosh	68	1.47
Esopus	Rome Beauty	100	2.0
Esopus	Stayman	108	none
Esopus	Wagener	113	15.93
Esopus	Winesap	105	0.95
Esopus	Winter Banana	109	11.01
Esopus	Yellow Newtown	116	7.76
Fallawater	Rhode Isl'd Greening	25	none
Fallawater	Winesap	23	none
Fameuse	Tompkins King	180	4.4

Table 7 (continued)

Blossom variety	Pollen variety	No. blossoms crossed	Per cent blossoms set fruit
Golden Sweet	Jonathan	130	none
Golden Sweet	Oldenburg	274	none
Gravenstein	Delicious	99	16.16
Gravenstein	Esopus	57	none
Gravenstein	Fameuse	81	8.64
Gravenstein	Jonathan	34	17.65
Gravenstein	McIntosh	94	45.74
Gravenstein	Red Astrachan	26	76.92
Gravenstein	Yellow Transparent	25	72.
Jonathan	Baldwin	28	none
Jonathan	Ben Davis	97	8.25
Jonathan	Delicious	103	8.74
Jonathan	Gravenstein	74	none
Jonathan	Grimes Golden	100	19.
Jonathan	McIntosh	100	3.0
Jonathan	McIntosh	107	14.02
Jonathan	McIntosh	91	14.29
Jonathan	Oldenburg	50	8.0
Jonathan	Rhode Isl'd Greening	64	none
Jonathan	Rome Beauty	110	17.27
Jonathan	Rome Beauty	150	16.67
Jonathan	Stayman	85	none
Jonathan	Tompkins King	24	none
Jonathan	Wagener	79	7.59
Jonathan	Wealthy	51	11.76
Jonathan	Winesap	104	none
Jonathan	Winesap	24	none
Jonathan	Winter Banana	99	3.03
Jonathan	Yellow Newtown	55	1.82
Jonathan	Yellow Transparent	24	4.17
Longfield	Baldwin	26	25.9
Longfield	Rhode Isl'd Greening	25	44.0
Longfield	Wealthy	25	32.0
Longfield	Winesap	26	none
McIntosh	Baldwin	26	38.46
McIntosh	Esopus	99	40.4
McIntosh	Golden Sweet	144	0.69
McIntosh	Grimes	101	49.5
McIntosh	Red Astrachan	27	55.55
McIntosh	Stark	309	none
McIntosh	Stayman	168	none
McIntosh	Tompkins King	307	.98
McIntosh	Yellow Newtown	103	11.65
Rome Beauty	Ben Davis	151	11.92
Rome Beauty	Delicious	73	10.92
Rome Beauty	Esopus	154	5.84
Rome Beauty	Grimes	50	46.0
Rome Beauty	Jonathan	154	5.84
Rome Beauty	McIntosh	27	33.33
Rome Beauty	McIntosh	64	none
Rome Beauty	Salome	136	27.94
Rome Beauty	Stayman	77	none

Table 7 (continued)

Blossom variety	Pollen variety	No. blossoms crossed	Per cent blossoms set fruit
Rome Beauty	Tompkins King	60	none
Rome Beauty	Wagener	152	14.47
Rome Beauty	Winesap	94	none
Rome Beauty	Winesap	41	14.63
Rome Beauty	Yellow Transparent	27	37.0
R. I. Greening	Esopus	102	none
Salome	McIntosh	98	13.27
Stark	Golden Sweet	131	none
Stayman	McIntosh	50	2.0
Stayman	Wealthy	33	none
Twenty-Ounce	Esopus	87	6.9
Twenty-Ounce	Gravenstein	38	none
Twenty-Ounce	McIntosh	46	2.17
Wagener	Ben Davis	105	7.62
Wagener	Delicious	98	4.08
Wagener	Esopus	96	none
Wagener	Gravenstein	65	20.00
Wagener	Jonathan	92	3.26
Wagener	Jonathan	57	8.77
Wagener	Rhode Isl'd Greening	47	6.9
Wagener	McIntosh	94	none
Wagener	Rome Beauty	100	26.0
Wagener	Rome Beauty	93	1.08
Wagener	Stayman	99	none
Wagener	Tompkins King	25	8.0
Wagener	Winesap	115	none
Wagener	Winter Banana	99	none
Wagener	Yellow Newtown	96	none
Winesap	Delicious	140	none
Winesap	Delicious	145	none
Winesap	Esopus	159	none
Winesap	Jonathan	150	none
Winesap	Rome Beauty	153	0.65
Winesap	Wagener	158	none
Winesap	Winter Banana	103	none

In the tests for inter-sterility of varieties, the results secured were not uniform. A few of the tests showing the greatest variation are here listed to emphasize this point.

Jonathan pollinized by McIntosh	3%
Jonathan pollinized by McIntosh	14%
Rome Beauty pollinized by McIntosh	33%
Rome Beauty pollinized by McIntosh	0%
Wagener pollinized by Jonathan	3%
Wagener pollinized by Jonathan	8%
Wagener pollinized by Rome Beauty	26%
Wagener pollinized by Rome Beauty	1%

Self-sterile, self-fertile, inter-sterile and inter fertile, are relative and not positive and negative characteristics and seem to vary with the general well-being of plant and environment in which the plants are growing. The character of weather at blossoming time is of importance in determining the degree of sterility that may exist. The self-sterility and inter-sterility of varieties may often cause light crops of fruits and a single test showing self-fertility of a variety is not a safe basis for broad and final conclusions. That phase of the problem is a subject for further investigation and can not be reported upon here.

The degree of self-fertility and inter-fertility, desirable in commercial orchards is theoretically not less than twenty per cent. In some orchards five per cent would produce good crops, but if the trees are well pruned and the top thinned to produce high-colored fruit a better rating may be desirable. In the commercial orchards of the state there are seldom less than two and usually three or more varieties close enough together so that inter-pollination is abundant. The following varieties of apples are the ones grown in greatest quantity in the state: Arkansas Black, Arkansas, Ben Davis, Black Ben Davis, Delicious, Esopus (Spi'zenburg), Gano, Grimes Golden, Jonathan, Rome Beauty, Stayman, Wagener, Winesap, Winter Banana and Yellow Newtown. There are several other varieties grown in commercial quantities but the list is short, compared to that grown in most of the eastern states. In all of the enquiries made in visiting the orchards and in correspondence, there has not been found an orchard containing two or more of the common commercial varieties here listed that is showing indications of failure due to self-sterility or inter-sterility of varieties.

INFLUENCE OF POLLEN ON FRUIT

Wicks (10) worked with Ben Davis, Jonathan, Winesap and Golden Grimes and obtained consistent results showing that the variety of pollen exerted no direct influence in modifying the shape, color or quality of the apple. Some have found that cross-pollination increased the size of the fruit but these

investigators did not dissociate perfection or completeness of fertilization and its resulting stimulus to the growth of the fruit from variety influence as such. The crosses made in this work gave a good opportunity to study the influence of the variety of pollen. In no case was there a modification of the size, shape, color or quality of the fruit to such a degree as to suggest that the variety of pollen was a causal factor in such a variation.

CROSS-POLLINATING AGENTS

Apple blossoms are visited by a great many varieties of insects. Bees were more numerous than any other species in the orchards in which notes were taken for our work. Their abundance and great activity seem to justify the conclusion that they are very important pollen-conveyors, but we have not been able to find conclusive evidence that they are a necessity for successful cross-pollination. Bees travel long distances in visiting blossoms, but in many sections of Washington there have been many orchards fruiting quite satisfactorily without any tame bees known to be within several miles.

The abundance of many kinds of insects at the blossoming period, and the eagerness with which they visit the blossoms, would seem to indicate that in many districts the orchard pollination work is quite satisfactorily done by other insects.

Wind is not effective as a cross-pollinating agent. Lewis and Vincent (9) report that field tests gave evidence that apple pollen is not carried from tree to tree by the wind and that it is seldom carried far from the tree top in which it is produced. Waugh (7) found similar conditions existing in plum pollination. The fresh pollen of apple blossoms is not dry and dust-like and is not easily moved by wind. The pollen collected from the old dried stamens sticks to any object that it touches. Tests were made by using a fan and anemometer to create and measure air-movement. Blossom clusters in various stages of development were exposed to wind and the results carefully noted. Wind blowing ten miles per hour did not remove the pollen from the stamens, and wind blowing twenty miles per hour did not carry the pollen from the blos-

som clusters and adjoining leaves. Wind blowing ten miles per hour did cause the stigmas to be well supplied with pollen from the same flower.

JUNE DROP

June drop has long been claimed to be the result of lack of pollination, although little work of a definite character has been done on the problem. Heinicke (13) gives the seed content of apples that had fallen and those that were still attached to the tree. The figures show clearly that the seed content of the attached apples is greater than of the fallen fruit, but no distinction was made between the seed coats that contained kernels and those that did not. He suggests "that other factors, in addition to fertilization or pollination are responsible for the set of fruit."

June drop of apples as it has occurred in the Experiment Station Orchard, Pullman, Washington, is not limited to the month of June. The apples fall almost continuously from the fall of the blossoms to the maturity of the fruit. The fall of the flower stems begins a few days after the petals drop. If the weather following the blossoming period is very dry and windy or very cool the fall is very rapid, but mild weather with little wind causes the flowers to fall more slowly. Trees that are in vigorous condition also retain the flowers and flower stems longer than those that are poorly nourished. Varieties differ also, in this activity. The Jonathan drops its blossom material quickly and quite completely. The Esopus (Spitzenburg) retains many of its flower stems throughout the entire growing season. The most rapid fall of June drop fruits takes place before mid-summer. In the years most favorable to fruit production many June drop fruits attain a diameter of one inch before they show signs of falling.

SEED CONTENT OF JUNE DROP APPLES

In order to gain information about the relation of June drop to seed production, fallen apples were gathered from the ground under the tree and the seed content ascertained. The results are shown in Tables 8 and 9. The orchard in which this

material was gathered was then about sixteen years old and was a mixed planting of Jonathan, Rome Beauty, and Gano varieties.

Table 8 contains data in which a distinction was made between normal seeds and seeds that started to develop but did not contain embryos. The fruits generally contained seed coats which varied greatly in the degree of plumpness. Some of the seed coats were empty and others were only partially filled. The latter contained a whitish translucent material, but upon careful examination we found that it was not an embryo. These seed coats were not counted as seed. The normal seed could be easily distinguished by the pure white color of the flesh and the true cotyledon. This same distinction is made in Table 9.

Table 8, A Comparison of the Seed Content of Permanent Set and June Drop Jonathan Apples—Crop 1918

Lot No.	No. of apples	Diameter of apples in inches	No. of fruits containing normal seeds
1	63	$\frac{1}{4}$ - $\frac{1}{2}$	none
2	21	$\frac{1}{2}$ - $\frac{3}{4}$	none
3	24	$\frac{3}{4}$ - 1	4
4	53	1 - $1\frac{1}{4}$	53

Lots No. 1 and 2—Fruits were gathered from the ground.

Lot No. 3—Fruits were still attached to the fruit spurs but the stems had turned yellow and were easily removed when gathered July 17th.

Lot No. 4—Fruits were green and apparently normal permanent set, gathered July 17th.

Table 9 is a record of the seed content of June drop and hand-picked apples grown under different cultural conditions in the same orchard. The field peas were planted in early spring for the purpose of producing an early drouth effect. The Jonathan tree in the field pea plot showed plainly the effects of drouth in the middle of July when the fruits were gathered. The Rome Beauty trees were on a little lower ground and at that date were showing no indication of suffering for water. All of the trees in the clean culture plots were growing vigorously and showed no indications of drouth.

Table 9, Shows the Seed Content of June Drop and Hand-Picked Apples of Jonathan and Rome Beauty Varieties—1919

Variety	Soil treatment	Kind of fruit	Date collected	No. apples counted	Per cent of apples containing seed in only					
					1 cell	2 cells	3 cells	4 cells	5 cells	6 cells
1. Jonathan	Field peas	June drop	July 5	1000	47.9	27.1	18.4	6.6	0	0
2. Jonathan	Clean culture	June drop	July 5	982	62.2	18.4	8.1	5.3	0	0
3. Jonathan	Clean culture	Hand picked	July 7	325	0	0	0	4.8	27.6	67.6
4. Rome Beauty	Field peas	June drop	July 5	991	55.6	22.2	15.3	6.8	0	0
5. Rome Beauty	Clean culture	June drop	July 5	900	53.3	21.2	15.7	7.8	0	0
6. Rome Beauty	Field peas	Hand picked	July 7	400	0	0	0	6.5	22.3	71.2

The fact that all fruits not containing normal seed did not drop immediately following the fall of the petals is illustrated in Figure 1, which shows a cluster of Gano fruits ranging in size from that of apples immediately succeeding the fall of petals to fruit one inch in diameter. Only the large fruit in the center contained seed. The smallest fruit contained only rudimentary seed coats. The other three contained seed coats that were badly shriveled, but did not contain kernels. All but



Figure 1. Cluster of Gano apples.

the large fruit in the center were essentially June drops, as the stems had turned yellow and they were easily separated from the spur. The largest fruits in Figure 2 contained five and four seeds each respectively. The others which are June drops contained only empty seed coats. In Figure 3 the two



Figure 2. Cluster of Jonathan apples.



Figure 3. Cluster of Rome Beauty apples.

largest fruits contained five seeds each and the others which were June drops contained only empty seed coats.

The evidence indicates that lack of fertilization of the flowers is a causal factor in the June drop of apples. Factors of environment that would tend to create sterility or increase the degree existing would probably tend to cause the abscission

of weaker fruits and those in which only a small per cent of the ovules are fertilized. A good list of inter-fertile varieties properly planted will form an orchard that will fruit with the minimum loss by June drop.

SEED CONTENT OF APPLES

The seed content of the apples varies greatly in the different varieties. Heinicke (13) and Crandall (14) show that large fruits contain a greater number of seed per apple than small fruits of the same variety. Heinicke shows that there are other factors than seed content influencing the size of fruit.

In order to study the influence of the seed content on the growth and development of the fruit, 100 clusters of Jonathan apples in which there were two fruits of equal size, were located, the fruits gathered and the seed content ascertained. On the same date 100 clusters of two fruits each of unequal size, were located, and the seed content noted. This is shown in Table 10 and indicates the relation of the seed content to the size of the fruit.

The apples containing the greatest number of seeds grow more rapidly throughout the season. The size of the individual fruit may be modified by location, with reference to the vigor of the spur to which it is attached, and the abundance of nearby foliage. The high seed content, however, seems to stimulate development during the entire growing period.

The material from which Table 10 was compiled was collected August 12th and showed a very great variation in size and shape. The large fruits in the clusters of unequal size averaged

Table 10, A Comparison of the Seed Content of Jonathan Apples Borne in Clusters of Two Fruits—August, 1919

Character of cluster		No. fruits	Average No. cells containing cells
Fruits of equal size	Fruits of highest seed content	100	3.9
	Fruits of lowest seed content	100	2.52
Fruits of unequal size	Large	100	4.45
	Small	100	2.94

the largest in size of all fruits used. They were also the most uniform and best-shaped of any of the four lots. The fruits of equal size were usually well formed and of intermediate size. The smallest fruits were most frequently one-sided in

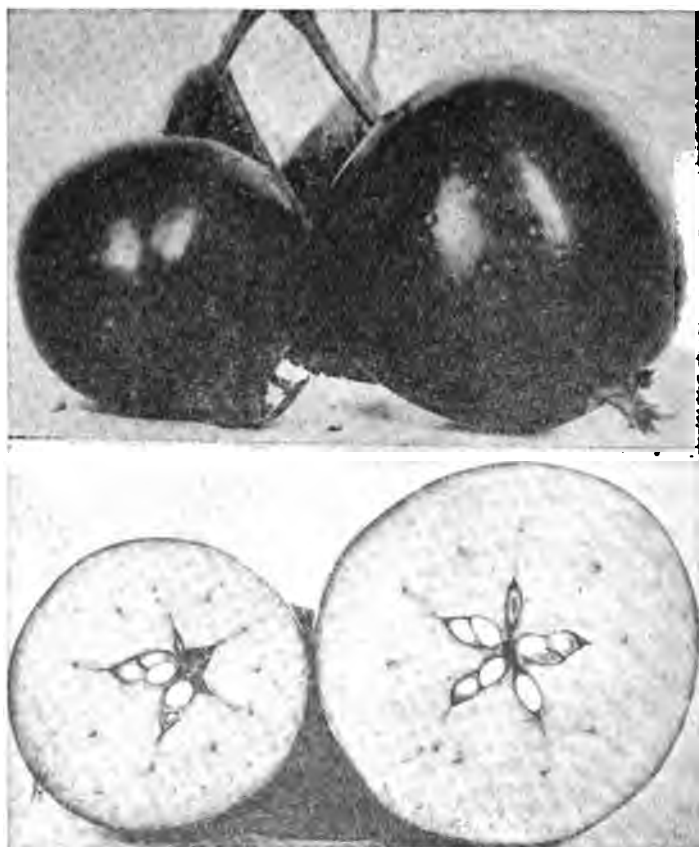


Figure 4. Cluster of two Jonathan apples.

radial diameter as well as in length. The location of the fruit in the blossom cluster seemed to have no relation to its size. The small fruit was as frequently the center of the terminal blossom as the largest, and the clusters of fruit of equal size had about as many terminal fruits as did the other set. Figure

4 shows two views of a cluster of two Jonathan apples of unequal size.

SEED CONTENT OF ONE-SIDED APPLES

Further study of the influence of the seed content of apples on size and shape of fruit was made on the Gano, Jonathan and Rome Beauty varieties. The apples were sorted into two groups, the first of well-formed fruits, and the second of fruits one side of which was longer than the other. No attention was given to the lateral radii in this classification except in the lot designated as "Special" in Table 15. Apples of the types represented by both figures five and six were included in the one-sided group. The fruits were cut and a careful record made of the number of seeds in each and the location of the vacant cells in the one-sided fruits. Data showing the seed content of these lots are presented in Tables 11 to 15, inclusive.

Relatively few of the apples classed as one-sided would have been classed as misshapen in commercial grading. The number of fruits given in each lot in the tables does not indicate the relative number of such fruits in the crop. On July 17, 1919, of 764 June drop Rome Beauty apples gathered 46.3% were one-sided; and of 803 June drop Jonathan apples gathered on the same date, 17.8% were one-sided. June drop and hand thinning usually remove nearly all of the apples that are so one-sided as to be classed as misshapen.

The size of the fruit was a fair index of the seed content. The larger the fruit the larger the number of seeds it contained. In every class of small, medium-sized, large, and very large fruits, the well-formed fruits contained more seeds than did the one-sided fruits.

The one-sided fruits in which all seed cells in the core contained seeds, averaged nearly as great a seed content as the well-formed apples, but there was a greater percentage of the one-sided apples that had vacant cells in the core than in the well-formed fruits. This seems to be the basis of the difference in total seed content and its relation to the form and size of the fruit more definitely than the number of seeds in each cell. The figures presented in Tables 12 and 13 and 14 indicate

that the average seed content per cell of the filled cells in the fruit is practically the same in the one-sided and in the well-formed fruits of the same size. In these tables it is clearly indicated that the vacant cells of the fruit are closely associated with the form of fruit and with the size.

LOCATION OF VACANT CARPELS IN APPLES

The location of the vacant cells in the fruit is summarized in the data presented in Table 15. From 21.7% to 34% of the fruits of the Gano apple had vacant cells in the short side only. The largest percentage of the vacant cells was in the short side of the smaller fruits. The larger fruits show a smaller percentage with vacant cells and a stronger tendency to develop in normal form. The same is true in all varieties worked upon.

The lot designated as "Special" in Table 15 is Jonathan and includes only the fruits that have unequal lateral radii. This

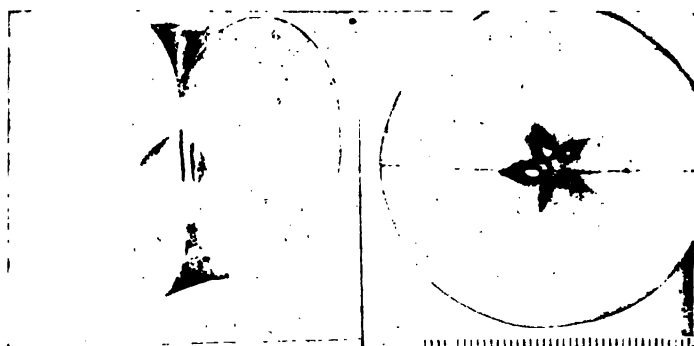


Figure 5. Longitudinal and cross-section view of a typical one-sided Jonathan apple.

lot is illustrated by Figure 6. The effect of empty carpels in modifying the form of the fruit is more striking in this lot than in any other. It was necessary to sort over 1000 to secure the 60 specimens used.

The basis of blossom fertilization for perfect fruit production is here indicated to be the five carpels in each blossom, and unless such complete pollination and fertilization is ac-

complished imperfect fruits will be abundant in the crop. The seed development is not an absolute necessity for the fruit development, but the seed content of the fruits recorded in these tables indicates that the seed development in each cell of the core stimulates most directly the development of the flesh adjacent to that cell.

Figure 6 illustrates the condition commonly found in apples



Figure 6. Longitudinal and cross-section view of a misshapen one-sided Jonathan apple.

Table 11, Showing the Average Seed Content of One-sided and Well-formed Apples of Different Sizes

Variety	Small apples		Medium apples		Large apples		Very large apples	
	One-sided	Well-formed	One-sided	Well-formed	One-sided	Well-formed	One-sided	Well-formed
Gano—								
Total No. apples	203	594	239	932	190	872	115	784
Av. No. seeds per apple .	5.8	6.8	6.6	6.8	7.2	7.7	7.7	7.9
Jonathan—								
Total No. apples	241	260	229	271	173	326		
Av. No. seeds per apple .	4.4	4.9	4.5	6.8	5.2	7.2		
Rome Beauty								
Total No.	569	1232	452	1492	250	1273	105	809
Av. No. seeds per apple .	6.2	6.2	7.	7.7	7.7	8.3	8.3	9.2

which are very much one-sided. Two or more adjacent vacant cells are quite uniformly in the small side of the fruit. Fruits with one vacant cell are well illustrated in Figure 5. The vacant cell in such fruits is frequently located independently of any one-sided development that may exist. Very few clearly one-sided fruits were found which did not contain vacant cells in the short or small side.

Table 12, A Comparison of the Number of Vacant Cells in One-sided and Well-formed Gano Apples

	Small apples		Medium apples		Large apples		Very large apples	
	One-sided	Well-formed	One-sided	Well-formed	One-sided	Well-formed	One-sided	Well-formed
Total No. apples ..	203	594	239	932	190	872	115	784
Per cent of apples with all seed cells filled	32.	46.1	43.9	55.6	53.7	65.8	67.8	69.6
Per cent of apples with one vacant cell	32.	33.3	39.3	30.5	32.6	27.5	25.2	26.3
Per cent of apples with two or more vacant cells	35.5	16.3	16.7	14.	13.7	6.6	6.7	4.2

Table 13, A Comparison of the Number of Vacant Seed Cells in One-Sided and Well-Formed Jonathan Apples

	Small apples		Medium apples		Large apples	
	One-sided	Well-formed	One-sided	Well-formed	One-sided	Well-formed
Total No. of apples	240	260	229	271	173	326
Per cent of apples with all seed cells filled	24.1	31.2	15.3	47.9	20.8	55.8
Per cent of apples with one vacant cell	23.7	29.2	22.3	23.9	24.8	28.2
Per cent of apples with two or more vacant cells	51.8	39.2	62.4	28.0	44.4	15.9

Table 14. A Comparison of the Number of Vacant Seed Cells in One-Sided and Well-Formed Rome Beauty Apples

	Small apples		Medium apples		Large apples		Very large apples	
	One-sided	Well-formed	One-sided	Well-formed	One-sided	Well-formed	One-sided	Well-formed
Total No. apples ..	569	1232	452	1497	250	1273	105	809
Per cent of apples with all seed cells filled	28.3	54.	42.2	62.3	56.4	69.7	62.1	76.2
Per cent of apples with one vacant cell	34.4	32.9	35.2	28.9	30.4	25.3	32.4	21.5
Per cent of apples with two or more vacant cells	37.3	13.	22.6	8.7	13.2	5.	5.7	2.3

Table 15, Showing the Distribution of Vacant Seed Cells in One-Sided Apples

Variety	No. of fruits	% fruits without vacant cells	% fruits with vacant cells on short side only	% fruits with vacant cells on long side only	% fruits with vacant cells on each side
Gano	747	49.3	29.5	11.5	9.5
Jonathan	470	19.7	28.8	12.9	38.6
Rome Beauty	1376	47.2	29.2	18.2	5.4
Special	60	10	58.3	1.6	30.0

SUMMARY

Self-sterility is more common among varieties of apples than is self-fertility.

Self-fertility is not a fixed character but varies with the general well-being of the fruiting spurs of the tree.

The period of viability of the pollen is not a limiting factor in blossoming fecundation.

Varietal differences in pollen exert no direct influence on the size, shape, color or quality of the fruit produced.

Insects are the principal cross-pollenizing agencies in apple orchards.

The failure of the apple to produce seed is intimately associated with June drop. June drop fruits contain few or no seeds.

The number of seeds that apples contain varies in proportion to the size of the fruit.

Apples that are extremely one-sided so that the lateral radii are markedly unequal usually have empty carpels in the small side and filled ones in the large side.

In Washington the most popular commercial varieties of apples seem to be satisfactorily inter-fertile.

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STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISION OF SOILS

INVESTIGATIONS IN DRY
FARM TILLAGE

By

M. A. McCALL and HENRY F. HOLTZ

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**In co-operation with the United States Department of Agriculture.

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Figure 1. A relief map of the State of Washington, showing the location and extent of the area within the state receiving less than 15 inches of annual rainfall. Typical points, within and without the area, are designated to show variation in altitude, annual rainfall, soil type, etc. Figure 2 and table 3 give these variations.

Investigations in Dry Farm Tillage

FOREWORD*

Location and Control of the Branch Station:

The Adams Branch Experiment Station was established in 1915 for the investigation of dry farming problems. The station farm, located 3 miles northeast of the town of Lind, is the property of Adams County, being leased at a nominal figure to the Washington Agricultural Experiment Station for experimental purposes. Until September 30, 1920, the Office of Cereal Investigations, Bureau of Plant Industry, United States Department of Agriculture, co-operated in maintaining the station.

The field work of the experiments reported in this bulletin was done on the Adams Station farm.

Limitations in Applying Results and Conclusions:

Dry farming is used in a very elastic way to designate the growing of crops without irrigation under a wide variety of semi-arid to arid conditions. In this bulletin the term is limited to apply only to the typical summer-fallow system practiced in the Western United States under conditions where natural precipitation is the direct limiting factor in crop production. The prime object of the summer-fallow, in this case, is the conservation of moisture; and the affect of tillage variations on the moisture content of the soil following the year of fallow is the chief factor which makes one method or system superior or inferior to another.

It is taken for granted that the summer-fallow and its place are generally understood by the readers of this bulletin.

*Acknowledgement. The authors wish to acknowledge the helpful advice of Prof. F. J. Sievers, Head of the Department of Soils of the State College of Washington, and the suggestions of Mr. H. M. Wanser, Assistant in Soils and Crops on the Adams Branch Experiment Station, and to thank Mr. Dan Krehbiel, Lind, Washington, for supplying his rainfall record for the period 1897-1906.

Opinion may vary as to the average, annual rainfall above which the summer-fallow system is unnecessary, but within the limits hereafter outlined there can be no doubt of its necessity.

It is difficult, if not impossible, to place definitely the annual precipitation below which moisture becomes the **direct** limiting factor in production. In this general area, however, observation and experimental evidence indicate that with an annual rainfall of 15 inches or more, the beneficial effects of the fallow on yield are due not so much to added moisture, as to the influence of tillage on nitrification. Each year, as rainfall is above or below normal, this limit varies in either direction, and it cannot be assumed, therefore, to define exactly the area where the chief purpose of the fallow is to conserve moisture. However, as a rough dividing line, it will serve as well as any other.

Experimental data will be discussed and applied, therefore, in the light of conditions as found in that part of Washington where the annual rainfall is 15 inches and less. (See Figure 1). The results, however, are most directly applicable to the localities of lower rainfall in this area. In any case, it must be understood that conclusions and suggestions are based on soil and climatic factors, and especially on the amount, nature and distribution of rainfall peculiar to this region as a whole.

Where the beneficial effects of the fallow are due almost entirely to the influence of tillage on nitrification, the suggestions of this bulletin are not intended to apply.

THE EXTENT AND IMPORTANCE OF DRY FARMING IN WASHINGTON

The preliminary report of the 14th census, issued by the Bureau of the Census, United States Department of Commerce, places the improved farm lands of the state in 1920 at 7,129,243 acres. The same report shows the improved acreage receiving a rainfall of 15 inches or less, assumed in this case as the limit of dry farming, to be, exclusive of irrigated lands, approximately 3,161,500 acres. (This latter figure is partly estimated in certain counties on the dividing line, but the estimates, based on U. S. Weather Bureau statistics, are con-

servative). On this basis, 45 per cent of the present improved area of the state is dry farmed. Contemplated irrigation will probably eventually cover the drier lands of this district, yet allowing for a maximum development of irrigation, when the shifting nature of the limit assumed for dry farming is considered, it is reasonable to estimate that 20 to 25 per cent of the state's total improved acreage will always be dry farmed if continued in production.

In 1919, the state produced in round numbers 40,000,000 bushels of wheat. The district receiving less than 15 inches of rainfall produced 15,100,000 bushels, or 37.5 per cent of the total (1).

CLIMATE AND RAINFALL

The geography and topography of central Washington have such an important bearing on climate, that they should be briefly considered in discussing this factor (2).

This portion of the state is a more or less rolling plateau, with a generally increasing elevation from the south and west toward the north and east. (See Figure 1). On the west are the Cascade Mountains. These mountains shut off the district from direct oceanic influence, and have a decided effect on prevailing climate.

Prevailing winds are from the west, and are the chief source of precipitation. In crossing the mountains much of the moisture is lost from the air in rain or snow. When this same air descends on the eastern slopes, due to increasing temperature with pressure (2), its moisture capacity increases. The result is a region of low rainfall and high evaporation east of the mountains.

After the air currents have passed on over the low interior valleys and again rise toward the north and east, their moisture holding capacity gradually decreases, and there is a more or less regular increase in annual rainfall with increase in altitude. Local changes in topography, as they influence local air-currents, may modify local rainfall, but for the area as a whole the above general statement holds true. (See Table 1).

The wide, treeless plains offer little obstruction to the passage of winds, which at certain periods, are almost constant. The evaporative affect of these winds complicates the moisture problem, and the blowing of certain lighter soil types adds to the difficulties of tillage.

Temperatures vary over rather a wide limit. During each summer there are periods when at some point the temperature goes as high as 100 degrees F., or more, and winter temperatures may go as low as 20 or 30 degrees F. below zero, but in either case such periods are usually of short duration.

Evaporation is active during much of the year, and is especially important in its affects on moisture conservation during the fall and spring.

Precipitation occurs chiefly in the fall, winter and spring; and the summers are comparatively rainless. Rains are characteristically gentle, and are seldom of great volume at any one time. A portion of the precipitation always occurs as snow, the proportionate amount having an important bearing on tillage methods.

In Table 1 are given average annual rainfall and other comparative data for certain representative points within the area. (See Figure 1 for the location of these points). Monthly and annual precipitation data for the experiment station farm, covering the period from September 1st, 1897, to August 31st, 1906, are given in Table 2, and for the period of the experiments, September 1st, 1916, to August 31st, 1920, in Table 3. This division of the precipitation year is adopted because it conforms more nearly to the actual beginning of the fallow and the ending of the crop year than does the calendar year.

The data of Table 1 explain why results in crop yield or in the operation of different methods vary so widely within the area as a whole. A study of Tables 2 and 3 strikingly points out the severity of moisture conditions during the period of the experiments. The three tables, considered together, show that not only is there variation with locality, but also from year to year, or over a period of years for each individual locality. Granting the necessity of varying methods with locality, these data indicate the desirability of equal varia-

tion even on the same farm from year to year, and emphasize the necessity of a knowledge of the effect of these variations on the result of any given operation, in order to manipulate practice intelligently.

Table 1: Altitude, Annual Rainfall, Soil-Nitrogen, and Soil-Type as Measured by Silt Content, at Typical Points in Eastern Washington

Station	Altitude	Rainfall	Soil Nitrogen	Soil Silt	Distance
	Feet	Inches	Percent	Percent	Miles
Pasco	370	7.2	0.0115	20	0
Hatton	1100	9.7	0.0430		44
Lind	1750	11.8	0.0650	45	65
Ritzville	1850	12.6	0.0900		83
Sprague	1925	15.5	0.1260		108
Rosalia	2400	19.4	0.1700		138
Pullman	2550	21.5	0.2130	70	148

Note:—The data for rainfall and altitude are taken from U. S. W. B. reports. The nitrogen data are taken from Bul. 85 of the Washington Experiment Station and from original determinations by the junior author. The data on silt are from original data of the junior author. The distance given from Rosalia to Pullman is the west to east distance.

Table 2: Monthly and Annual Precipitation by Crop Years for the Adams Experiment Station during the Period from September 1st, 1897, to August 31st, 1906

Year	Monthly Precipitation (Inches)												Average Annual Inches
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	
1897-1898	0.23	0.28	1.64	0.00	0.85	0.81	0.16	0.28	1.37	0.00	0.13	0.69	6.34
1898-1899	0.26	0.34	1.37	0.71	1.88	1.31	0.27	0.96	0.57	0.40	0.03	0.66	8.76
1899-1900	0.44	1.63	2.63	1.23	0.68	1.25	0.90	1.47	0.88	0.49	0.06	0.54	12.00
1900-1901	2.29	1.95	1.47	1.78	1.36	2.54	0.63	0.31	0.91	1.26	0.60	0.04	15.34
1901-1902	1.24	0.15	0.85	0.36	1.68	2.53	0.63	1.79	2.22	0.07	0.58	0.23	12.33
1902-1903	0.59	0.26	3.56	2.49	1.79	0.45	1.23	0.37	0.35	0.26	1.25	1.07	13.67
1903-1904	0.22	0.57	2.95	2.00	1.09	2.14	2.63	1.35	0.47	0.68	0.79	0.14	15.03
1904-1905	0.03	0.35	0.36	1.13	1.94	0.43	1.40	0.92	2.12	2.63	0.02	0.03	11.34
1905-1906	0.69	2.23	1.05	1.46	1.36	1.79	0.66	0.07	1.65	0.61	0.02	0.42	12.01
													Average 11.87

Note:—This record, taken from U. S. W. B. reports, was kept by Mr. Dan Krehbiel, a portion of the period the meteorological station being located on the same section as that containing the Adams Experiment Station farm, and at no time farther than one and one-half miles distant. This record was discontinued with August 31st, 1906, and no other is available for the intervening period, September 1st, 1906, to August 31st, 1916.

Table 3: Monthly and Annual Precipitation by Crop Years for the Adams Experiment Station during the Period of the Experiments, September 1st, 1916, to August 31st, 1920

Year	Monthly Precipitation (Inches)												Average Annual Inches
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	
1916-1917	0.21	0.07	1.29	0.80	0.00	0.45	0.47	2.07	1.77	0.47	0.00	0.00	7.60
1917-1918	0.00	0.00	0.48	1.88	0.88	0.42	1.27	0.00	0.57	0.10	0.44	0.60	6.64
1918-1919	0.25	0.82	1.30	0.50	1.53	1.82	0.55	0.61	0.57	0.00	0.05	0.10	8.10
1919-1920	0.61	0.53	1.02	0.64	0.54	T	T	1.20	0.55	0.60	0.38	0.49	6.56
													Average 7.22

SOILS

The soils of central Washington are basaltic in origin. There are differences of opinion as to their early geologic formation, but in any case, they have undoubtedly been modified in recent periods, especially in location, by winds.

Soil type varies with elevation and rainfall, the sandier soils being found at the lower elevations, as is the lightest rainfall. Type grades through sandy loams, fine sandy loams, very fine sandy loams, and silt loams. The sandier types are subject to drifting. Figure 2, based on Table 1, shows graphically the relation of soil type, as measured in this case by silt content, to altitude and precipitation.

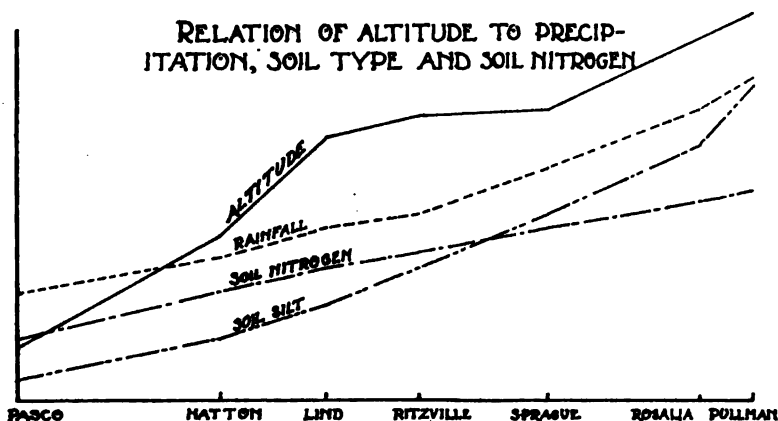


Figure 2. This graph is based on the data of table 3. It shows the uniformity of variation in rainfall and in soil type and condition throughout the dry-farming district of the state of Washington. Altitude at any given point in this area may be used as a rough measure in determining the probable value of the other factors shown in this graph. The different points taken as representative of this variation are shown on figure 1.

As an illustration of the uniformity of the soils of the area, and to identify the soil type upon which work was done, the mechanical analysis of the soil on the Adams Experiment Station farm by feet to a depth of four feet is given in Table 4.

Table 4: The Mechanical Analysis, by Feet, of the Soil on the Adams Experiment Station Farm

Sample	Fine Gravel	Coarse Sand	Medium Sand	Fine Sand	Very fine Sand	Silt and Clay	Total
1st Foot ...	0.00	0.08	0.13	9.82	45.88	45.05	100.96
2d Foot ...	0.00	0.08	0.08	8.68	46.75	44.40	99.99
3d Foot ...	0.00	0.11	0.14	8.04	52.01	39.70	100.00
4th Foot ..	0.00	0.06	0.05	6.10	50.24	43.45	99.90

This soil, a very fine sandy loam of the Ritzville series, is an average soil of the district. It is just on the border line of those types tending to drift, yet proper management will control that tendency. The great predominance of very fine sand and silt in its make up is evident. Physically, were it not for the tendency to blow, it would be an ideal dry farming soil. The wilting point of this soil is at a moisture content of about 3.8 per cent as determined after crop maturity, it being assumed that the crop, under the rather extreme prevailing condition, will remove the entire available moisture supply. When moist, this soil works into an ideal condition, but if tilled dry, the absence of clay and organic binding material causes a dusty, flour-like condition which is far from desirable.

The soluble salt content is high. This has a bearing on the availability of plant foods, and possibly on moisture relations. The continued efficiency of the soil mulch and certain problems in plow-sole formation are also influenced by this factor.

In essential plant food elements, this, and similar soils are reasonably well supplied. Potash and lime are abundant and phosphorus is relatively so. Nitrogen and organic carbon, the latter important chiefly because of its bearing on physical condition, are the soil elements most deficient.

INVESTIGATIONS

Much investigational work has been reported which covers ground similar to that of this bulletin. The most of this work, however, has been done under comparatively favorable dry

farming conditions, and suggestions based on such experimental results have not always applied under lighter rainfall.

The period covered by the experiments herein reported has been one of abnormally low rainfall with frequent, drying winds. (See Tables 2 and 3). This extreme condition has given prominence to the operation of certain principles, which it is believed are masked, if operative at all, under a more abundant moisture supply and a lower rate of evaporation. A study of climatic data indicates that as dry a period of similar duration may not immediately reoccur on the Adams Experiment Station, yet the condition is continuous in some of the drier sections of the state, and is of more or less intermittent occurrence in all localities.

All of these facts justify the offering of data covering a more limited time than might otherwise seem desirable.

FIELD OPERATIONS AND STUDIES

Field work in these experiments was done on two series of one-twentieth acre plots. These plots were alternately fallowed and cropped, one series being in fallow and one in crop each year. All were treated the same, except in preparing and maintaining the fallow. It was originally intended to use winter wheat in cropping, but seasonal conditions prevented adherence to this plan. The crops of 1918 and 1920 were spring wheat, Early Baart (Wash. 326), and that of 1919 was winter wheat, Turkey Red (Wash. 326). However, there is nothing in the data secured which indicates that this variation has in any way materially changed results.

Local practice limits tillage of the fallow after plowing to that necessary for weed control. In these experiments, the one variation from this practice was in the use of the spring-tooth harrow immediately after the plow, except in special cases, which are noted. A home-built weeder of the rod or bar type was used in controlling weeds. This was used twice each summer. Later, scattering weeds were cut with a hoe, this being the practice of the community. All plots were harrowed just previous to seeding. A hoe drill was used in this

latter operation, the ridging effect of this implement making it superior to other types for use on soils tending to blow.

A record of yield and other agronomic data was taken for each plot.

Tillage variations are given in the tabulation of data. (See Table 13).

SOIL SAMPLING

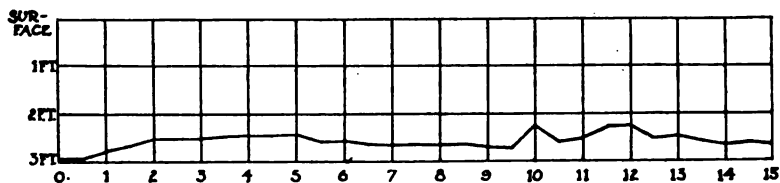


Figure 3. This diagram represents the penetration of moisture in a field soil on the Adams Experiment Station, March 7, 1921. Measurements were taken on the wall of a trench 15 feet long and 4 feet deep. It illustrates the necessity of taking soil samples to a standard depth well below the average depth of moisture penetration, and also the necessity of taking a comparatively large number of samples to secure reliable composites. In taking soil samples below the depth of moisture penetration, great difficulty is experienced in withdrawing the dry soil with an ordinary soil auger. Figure 4 illustrates a special auger used in this work.

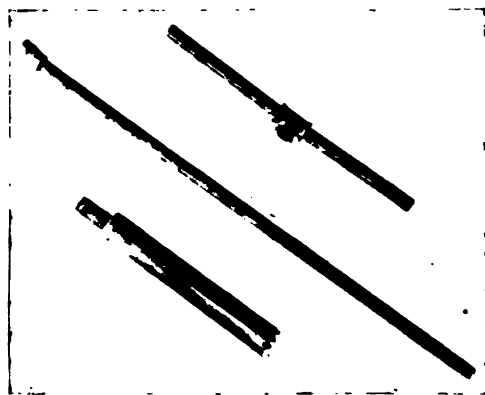


Figure 4. A Soil auger designed by the junior author, for taking samples in sandy soil types in the dry condition. This is a very satisfactory instrument.

MOISTURE AND NITRATE STUDIES

To determine as nearly as possible the cause of yield variations, moisture and nitrate-nitrogen data were secured each year, in the spring at the beginning of the crop season, and in the fall after the crop was removed. The end result is the true measure of the efficiency of any method or system, and the soil content of moisture and nitrate-nitrogen, at the beginning of the crop season after the year of fallow, are the most important data in this case. Limited facilities prevented more detailed studies.

Soil Sampling

One of the most prominent difficulties in soil investigations lies in sampling (3, 4, 5). In these studies, samples were taken on each of the two opposite end areas of the one-twentieth acre plots, the plots being 132 feet by 16.5 feet. Not less than three, and usually four borings were made in each area. Composites were then made by thoroughly mixing the entire mass of all borings to represent each area. Analytic determinations were made from these composites, the closeness of checking of the results from the two areas determining the necessity of further sampling. Sampling was continued until satisfactory checks were secured.

Moisture penetration in a field soil under dry farming conditions is not regular and uniform (see Figure 3), and it is not possible to take samples only to the depth of moisture penetration and secure results at all satisfactory. Accordingly all samples were taken to a uniform depth of four feet, this being well below the depth of average moisture penetration during the period of these experiments. This depth was also satisfactory for nitrate sampling, since the nitrates correspond in location to the soil moisture and are not found in appreciable amounts below the depth of moisture penetration.

The presence of a growing crop modifies soil condition and increases the probability of error. This is especially true of wheat after it has begun to tiller, the error before this period from crop influence being negligible. All sampling for these studies was done before the crop began to grow actively.

Analytic Methods

The moisture content was determined by drying 10-gram samples of the well mixed composites in an electric oven. The field soil on the station farm weighs 75 pounds per cubic foot on a moisture free basis. Using this weight, soil moisture was calculated in tons per acre to a depth of four feet.

Nitrate determinations were made by the phenoldisulphonic acid method (6) with modifications. This method has been questioned, but it is the best at hand for a study of this nature. The large number of samples to be run in a limited time make the simplicity and rapidity of the method strong factors in its favor. This is especially true on a branch station where laboratory help is limited. In any case, the probable error of field sampling (3, 4, 5) is greater than that of any method of analysis, and comparative data are the best that can be expected.

EXPERIMENTAL DATA

The use of the data secured in formulating conclusions might be questioned because of the comparatively slight spread observed in many instances, and because of discrepancies that occur. The low rainfall, however, naturally tends to bring all results to a more nearly common level, and percentage the differences are as large as are found with better yields. Slight differences, if isolated, are not a valid basis for conclusions, but in this case, where there are a comparatively large number of slight variations all pointing in the same general direction, it seems justifiable to use the data in developing at least general principles, provided not too great an emphasis is placed on detail. Unexplained discrepancies emphasize the need for additional investigation.

Yield data are more inconsistent than any other secured. There is a broad general relationship between grain yield and total soil moisture, and between straw yield and total soil nitrate-nitrogen, but unexplained exceptions are so frequent that by themselves yield data are not a valid basis for determining the real effect of tillage variations. Yield is the sum total result of all factors, and the factors are so little understood under dry farming conditions that apparent discrepan-

cies are not always explainable. In interpretation, therefore, moisture, nitrate-nitrogen, and yield data must all be considered.

In discussing practice in presenting the data, there are certain facts of universal knowledge which are taken for granted and are assumed in any discussion. Any practical farmer knows without it being specifically mentioned that **the fallow must be kept clean.**

In the presentation and later discussion of data it is intended to develop principles of moisture conservation, based on the data, and this point of view should not be confused by the reader with the management side of the problem. A statement of the superiority of any specific method in conserving moisture may be correct and necessary for a complete understanding of the operation of a given principle under all conditions, and yet the method from a management standpoint may be undesirable for various reasons. Where objections exist to any method or system from the management side of the problem they will be mentioned, but they will not be stressed in this discussion.

DATE OF PLOWING FOR FALLOW

The date of plowing is important, both directly in its effect on crop yield and indirectly in the distribution of labor.

It has been pointed out that variation in soil type and the amount of rainfall are general within the area covered by the discussions of this bulletin. (See Table 1 or Figure 3). It is necessary, therefore, in applying conclusions based on these data to the entire area, to consider the data from the standpoint of soil and climatic condition and the part that variation in such condition has had in the result.

Date of plowing should not be considered only as a matter of time, but rather as a matter of soil and climatic condition. The fall dates of plowing represent dry and wet plowing with a major moisture absorption period immediately following the plowing. The spring dates represent plowing done after the moisture absorption period is partially or completely passed for that season, and with a succeeding period of high evaporation before another major absorption period comes.

Each spring date is a variation within this variation. March 1st plowing is plowing done when the moisture content of the surface soil is largest in amount, early enough that evaporation is not as rapid as somewhat later, and while moisture is still falling on the newly turned soil. June 1st plowing represents the other extremes, the soil being dry, evaporation at a maximum, and rainfall having practically ended for the season. April 10th plowing is intermediate between the other two. At this date, total soil moisture is still practically as high as at the earliest date, but evaporation is more active and the plow layer is less moist and dries more quickly after turning. Less moisture also falls on the newly turned soil.

DATE OF PLOWING FOR FALLOW

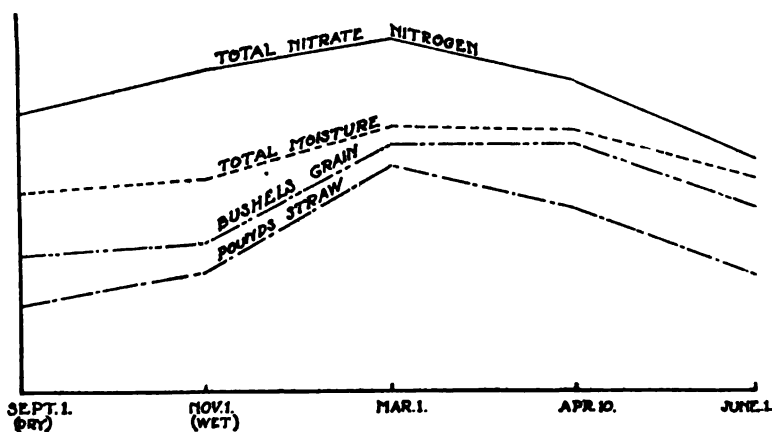


Figure 5. This graph is based on the data of table 5. It emphasizes the necessity of early spring work in preparing the fallow. It also shows that relationships exist between date (or condition), the basic soil factors, and yields. Grain yield more nearly parallels soil moisture content and straw yield the soil content of nitrate nitrogen. This indicates the greater relative importance of this latter factor under more favorable conditions.

These various considerations are not so important in the immediate presentation of the date as in later discussion, but are given at this time to emphasize the factor of condition in its bearing on all results. This will be developed more completely hereafter.

Table 5: Total Soil Moisture, Total Nitrate-Nitrogen, and Yield for Summer-fallow Plowed on Different Dates.
(Three Year Average)

Date of Plowing	Total Soil Moisture	Total Nitrate- Nitrogen	Yield per Acre	
			Straw	Grain
	Tons	Pounds	Bushels	Pounds
September 1st	521	66.8	6.6	350
November 1st	536	75.4	6.8	385
March 1st	589	82.2	9.0	500
April 10th	590	73.7	9.0	455
June 1st	534	55.9	7.3	380

In an analysis of these data, current opinion might well be considered. Early workers, almost without exception, advocated fall plowing of fallow, supposedly to insure absorption of winter precipitation and any beneficial effects that might accrue through alternate freezing and thawing of the plow layer. Widtsoe (7) recommends, "In the very great majority of cases over the whole dry-farming territory, plowing should be done in the fall." Somewhat later Cardon (8) and others (9) (10) point out that fall plowing is not superior to spring plowing, either in storing moisture or in producing crops. This is opinion from those areas most similar to that under discussion in this bulletin.

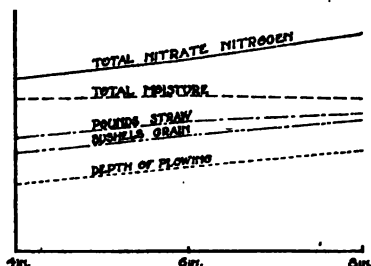
In this experiment, fall plowing, either wet or dry, has not given as good results as spring plowing. This is true both in soil moisture content and in yield. Nitrate development, particularly for the late fall plowing, is comparatively good in the fall plowed soil. Why yield has not at least equalled that of the late spring plowing is not entirely clear, but is probably due to the fact that the particular soil type tends to develop a somewhat run-together condition when worked up and allowed to stand over winter. Even with very careful tillage the following spring the influence of this condition may be more or less persistent. At any rate, the result corresponds to farm experience in this district.

Of the spring dates of plowing, the first two show practically equal results in soil moisture content and in grain yield. In nitrate-nitrogen content and in straw yield, the earliest plowing is superior. This means that in a season of more abundant rainfall, the earliest plowing has the founda-

tion for better grain yields as well. It is very evident that the latest spring plowing is inferior to that of the other two spring dates in every respect.

DEPTH OF PLOWING FOR FALLOW

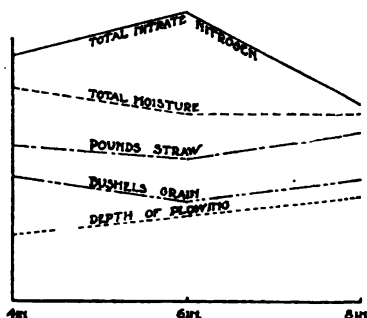
MARCH 1ST.



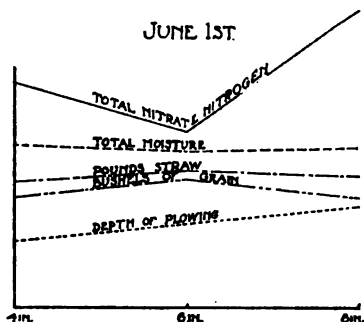
(a) The close parallel between depth of plowing, nitrate nitrogen, and yield of grain and straw on this date is apparent. See page 38 for a discussion of why deep plowing produces this result on this date.

(b) Instead of upward, the trend is downward with depth of plowing on this date. See page 38 in discussion of why result is different than that for March. Straw yield in general tends to follow the content of nitrate nitrogen, which would indicate the nitrate nitrogen data to be in error in this case. As the soil begins to dry, plowing should be more shallow.

APRIL 10TH.



JUNE 1ST



(c) There are no advantages in deep plowing for June. A discussion of the probable reasons are given on page 37. Deep tillage in a dry soil is poor practice in this territory.

Figure 6: The three graphs of this figure are based on the data of table 6.

DEPTH OF PLOWING FOR FALLOW

Depth of plowing is important from two standpoints, the effect on yield and the cost of plowing. On this question farm opinion varies more than on any other, although there is apparent a growing tendency to plow less deep.

Many of the current ideas of what is good dry farming practice are the outgrowth of humid farming. Because of their experience under humid conditions, it is very difficult for many thorough and careful farmers to reconcile shallow plowing with "good farming." Yet after all, "good farming" is a relative term, and any practice is "good farming" if it produces consistently better results.

Three depths of plowing, four, six, and eight inches, on each of the three spring dates, are included in this experiment. Four inches is about an average of shallow plowing in actual practice. Eight inches is used as the other extreme because prevailing soil types would not seem to need excessively deep stirring. Six inches is intermediate and about an average in prevailing field practice.

Table 6: Total Soil-Moisture, Total Nitrate-Nitrogen, and Yield for Summer-fallow Plowed at Different Depths on Different Dates. (Three Year Average)

Date and Depth of Plowing	Total Soil Moisture	Total Nitrate-Nitrogen	Yield per Acre	
			Grain	Straw
	Tons	Pounds	Bushels	Pounds
March 1st—				
Four inches	591	75.1	7.9	430
Six inches	609	78.0	8.4	485
Eight inches . . .	608	82.2	8.9	510
April 10th—				
Four inches	608	73.1	8.6	425
Six inches	569	79.5	7.9	405
Eight inches . . .	569	66.0	8.5	445
June 1st—				
Four inches	538	57.9	7.3	375
Six inches	529	50.7	7.8	405
Eight inches . . .	541	69.1	7.3	395

Early opinion on depth of plowing for fallow is summarized by Widtsoe (7), "Deep plowing is always to be recommended for successful dry-farming," deep plowing being elsewhere designated as eight inches or over. Cardon more recently states (8), "With the data available, however, the question

seems to be not so much how deep to plow as how well to plow." Stephens (9) finds in favor of shallow plowing (four or five inches) for spring wheat, the plowing being designated as early and April 1st being the date of other early plowing in the same series of experiments. Others (10) (11) seem doubtful of the necessity for deep plowing.

In comparing the above data it is apparent that variations in soil moisture content as affected by depth of plowing, are not the same for all dates of plowing. Deeper plowing has been most efficient in moisture conservation on the earliest date, while the reverse has been true on the intermediate date. For the late date there has been practically no differences, but the general result is similar to that of the intermediate date. It is true that in no case is the spread large, but the differences are consistent and have been similar during the whole period of the experiments.

The results of this experiment explain why farmers in the drier localities tend to plow more shallow, and offer an interesting comparison of the effect of condition, as influenced in this case by date, on the result of a given operation. To apply these results, condition must be taken into account. In terms of condition, the earliest date is similar to the average of the more favored dry farming districts, and the intermediate and late dates are similar to the drier localities.

Nitrate-nitrogen content and yield are less clear cut in their relation to depth of plowing than is moisture content. For the earliest date, there is a regular increase in both nitrate-nitrogen content and in yield with increase in depth of plowing, but for the two later dates there is no apparent relationship. The latter data are chiefly valuable in emphasizing the fact, that deep plowing offers no advantage for the less favored conditions.

HARVEST DISKING BEFORE FALLOW

Disking immediately after harvest to kill weeds and to create a mulch, supposedly favorable for moisture absorption, has been universally advocated from the earliest days of dry farming. From a theoretical standpoint this practice would seem to rest on a firm foundation for all conditions, which

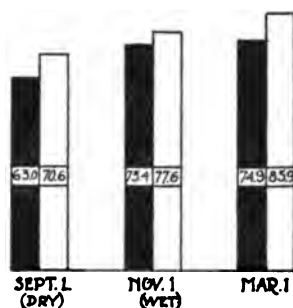
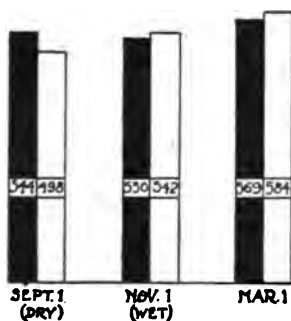
experimental evidence has shown it does in certain cases (15), but local experience has not confirmed this assumption as applying in central Washington.

HARVEST DISKING BEFORE FALLOW

SOIL

MOISTURE
TONS PER ACRE

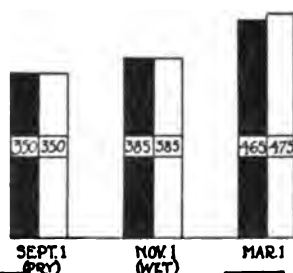
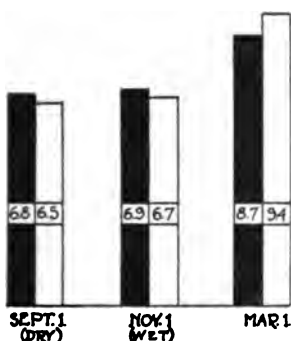
NITRATE NITROGEN
POUNDS PER ACRE



YIELD

GRAIN
BUSHELS PER ACRE

STRAW
POUNDS PER ACRE



DISKING IMMEDIATELY AFTER HARVEST.

NOT DISKED

Figure 7. This graph is based on the data of table 7. It compares harvest disking previous to plowing with no disking for three dates of plowing, two in the fall and one in the spring. The disking was beneficial before the dry September 1st plowing, but this in itself gave poor results. The dry work, either disking or plowing, is indicated by the graph to be poor practice. A discussion of dry disking and plowing and the reasons for their detrimental influence for the particular conditions of this district are given on page 36.

Table 7: Total Soil-Moisture, Total Nitrate-Nitrogen, and Yield for Summer-fallow With and Without Previous Harvest Disking.
(Three Year Average)

Treatment	Total Soil Moisture	Total Nitrate-Nitrogen	Yield per Acre	
			Grain	Straw
Plowed Sept. 1—	Tons	Pounds	Bushels	Pounds
Harvest Disked	544	63.0	6.8	350
Not Disked	489	70.6	6.5	350
Plowed Nov. 1—				
Harvest Disked	530	73.4	6.9	385
Not Disked	542	77.5	6.7	385
Plowed Mar. 1—				
Harvest Disked	569	74.9	8.7	465
Not Disked	584	83.9	9.4	575

Comparing the data for soil disked immediately after harvest and plowed dry September 1st, with that for soil not disked and also plowed dry September 1st, it is apparent that the former has a higher moisture content. It is reasonable to ascribe this advantage to killing weeds and so checking transpiration. On the other hand, when the November and March plowed plots of this treatment are compared in a similar way, the moisture advantage has changed. Except for the dry fall plowing, in itself poor practice, there seems, in this case, to be no advantage in disking stubble immediately after harvest. This agrees with farm experience and the findings of other investigators in this same general area (9) (10).

LATE FALL DISKING BEFORE FALLOW

If intending to disk stubble in the fall, the farmer has two alternatives. He may disk his soil while dry immediately after harvest, or he may wait until after fall rains and disk

Table 8: Total Soil-Moisture, Total Nitrate-Nitrogen, and Yield for Summer-fallow With and Without Previous Wet Fall Disking
(Three Year Average)

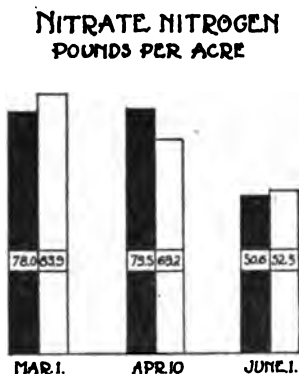
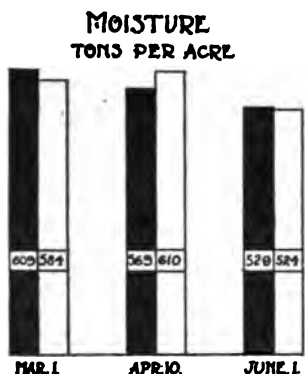
Treatment	Total Soil Moisture	Total Nitrate-Nitrogen	Yield per Acre	
			Grain	Straw
Plowed March 1—	Tons	Pounds	Bushels	Pounds
Wet Fall Disked	609	78.0	8.4	485
Not Disked	599	82.2	9.1	485
Plowed Apr. 10—				
Wet Fall Disked	569	79.5	7.9	400
Not Disked	590	72.3	9.3	465
Plowed June 1—				
Wet Fall Disked	529	50.6	7.8	405
Not Disked	540	57.6	7.3	410

his soil wet. Harvest disking has been shown to be poor practice. Is wet fall disking advisable?

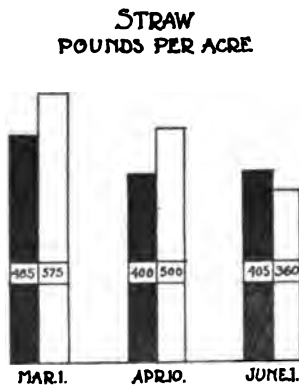
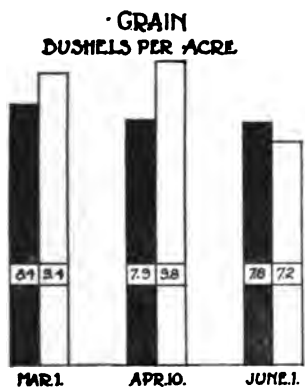
From these data, except that for total moisture for the March 1st plowing, there seems to have been a detrimental

LATE FALL DISKING BEFORE FALLOW

SOIL



YIELD



LATE FALL DISKING

No Disking

Figure 8. This graph is based on the data of table 8. It compares late fall disking previous to plowing with no disking for three dates of spring plowing. Results are variable, but at least indicate no advantage in favor of disking at this time. The date of spring plowing has more influence on the result than has the previous fall disking. Wet fall disking is discussed on page 40.

rather than a beneficial effect from the wet fall disking. Even in the case of the March 1st plowed plots, the grain yield indicates a possible error in the moisture date, for as previously

SPRING DISKING BEFORE PLOWING FOR FALLOW

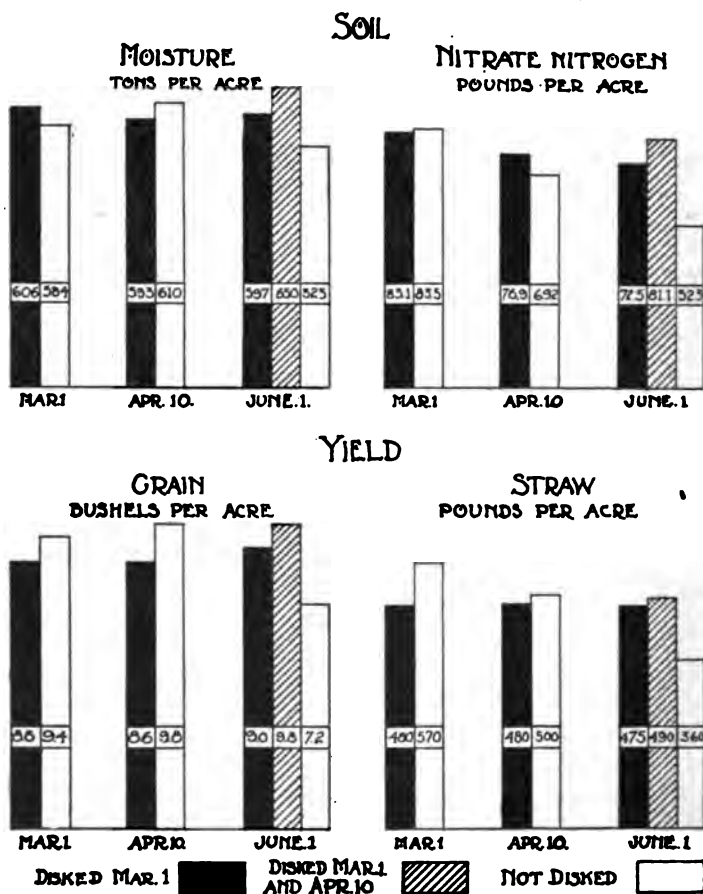


Figure 9. This graph is based on the data of table 9. It is a comparison of soils disked in the spring before plowing for fallow and those not disked. Disking has no advantage, except for late plowing, in which case an additional disking gives added benefits. The disking kills weeds and volunteer grain, and where the plowing date is so late that these drain soil moisture, it is good practice to disk. The shallow mulch of the disking does not interfere with absorption to the same extent as the deeper plowing.

pointed out there is a general relationship between grain yield and total moisture content. At any rate there has been, during the period of these experiments, no advantage in the practice.

SPRING DISKING BEFORE FALLOW

Spring disking, before plowing for fallow, has been advised for a number of reasons. The cutting up of weeds and stubble and their incorporation with the soil before plowing, the killing of early weeds and a delay in the plowing date to reduce the number of later weedings, and various effects in saving moisture where plowing must necessarily be, or is intentionally, late, have been advanced as arguments favoring the practice.

Table 9. Total Soil-Moisture, Total Nitrate-Nitrogen, and Yield for Summer-fallow with and Without Previous Spring Disking. (Three Year Average)

Treatment	Total Soil Moisture	Total Nitrate- Nitrogen	Yield per Acre	
			Grain	Straw
	Tons	Pounds	Bushels	Pounds
Plowed March 1—				
Disked March 1	606	83.1	8.6	480
Not Disked	599	82.2	9.1	485
Plowed April 10—				
Disked March 1	593	76.9	8.6	480
Not Disked	590	72.3	9.3	465
Plowed June 1—				
Disked March 1	597	72.5	9.0	475
Disked March 1 and April 10	650	81.1	9.8	490
Not Disked	540	57.6	7.3	410

This experiment shows no advantage in disking before plowing for either of the earlier dates of plowing. For the late date of plowing there is a decided advantage even in one disking, and this advantage is increased by a second disking on an intermediate date.

Growth of weeds and volunteer grain make no serious inroads on soil moisture previous to the intermediate date of plowing, but after that time their influence is evident. The benefit of the second disking probably lies both in weed control, and in the retentive qualities of the mulch. This lat-

ter consideration will be discussed more at length hereafter.

From the standpoint of effect on yield and moisture conservation, the spring disking and late plowing has been the most efficient system practiced on the station farm. In practical operation, on light soils, the system has disadvantages. Late plowed soil settles less than earlier plowing, has fewer clods and is pulverized more completely, and as a result is more inclined to blow. The use of the system should, therefore, be restricted to districts where soil blowing is not a problem.

IMMEDIATE VS. DELAYED CULTIVATION AFTER PLOWING

It is commonly recommended that the plow be immediately followed by the harrow to smooth and firm the soil, to work down irregularities, and to create a surface mulch. In the western portion of the area covered by the discussions of this bulletin, where soils tend to blow, farmers do not stir the soil after plowing until absolutely necessary to control weeds. The ordinary smoothing harrow pulverizes the prevailing soil types very completely and its use should be discouraged for this particular condition. Whether the after tillage should be discontinued if a more suitable tool could be used is not so clear. Delay in cultivating after the plow is also practiced under conditions where working down and firming the

Table 10: Total Soil-Moisture, Total Nitrate-Nitrogen and Yield for Summer-fallow With and Without Immediate Tillage After the Plow.

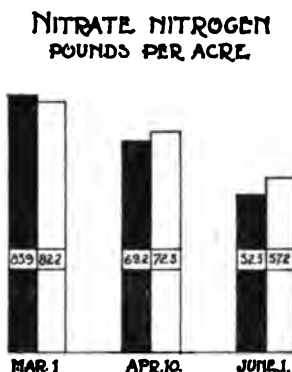
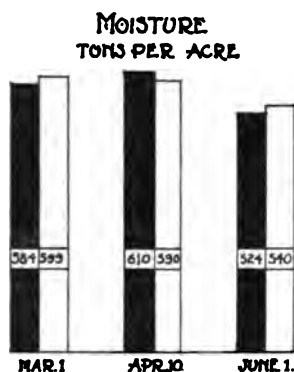
(Three Year Average)

Treatment	Total Soil Moisture	Total Nitrate- Nitrogen	Yield per Acre	
			Grain	Straw
Plowed March 1—				
Immediate Tillage	584	83.9	9.4	575
Delayed Tillage	599	82.2	9.1	485
Plowed April 10—				
Immediate Tillage	610	69.2	9.8	500
Delayed Tillage	590	72.3	9.3	465
Plowed June 1—				
Immediate Tillage	524	52.3	7.2	360
Delayed Tillage	540	57.6	7.3	410

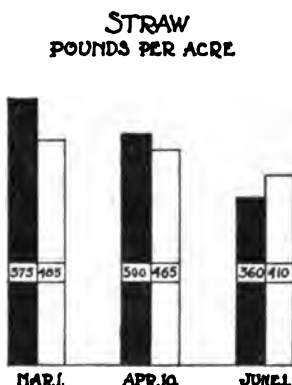
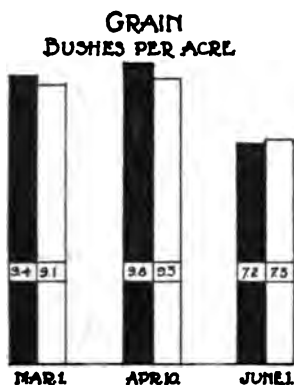
soil has a tendency to start early weed growth, the farmer, in this case, desiring to delay such growth in order to reduce

IMMEDIATE CULTIVATION OF FALLOW

SOIL



YIELD



CULTIVATION



No CULTIVATION



Figure 10. This graph is based on the data of table 10. It compares immediate and delayed cultivation of fallow on three spring dates. Except for the June plowing, which is so dry that the additional tillage has no settling effect, there seems to have been a slight beneficial result from the practice. The settled condition tends to give better absorption, and is especially desirable for the earlier dates when some moisture can still be expected before the dry summer season. On heavier soils with more abundant spring moisture, immediate tillage may be desirable. On light soils under more dry conditions, it has no place.

the number of necessary weeding and to delay the weeding operation until a time when other work is less pressing.

In this experiment, the plow was followed by a spring-tooth harrow. This tool ridges the soil, brings clods to the surface, and produces a condition more suited to resisting the wind than does any other available implement.

The 1918 moisture determinations for the plot plowed March 1st and given immediate tillage were for some reason in error, being undoubtedly too low, and their lack of accuracy was not checked until too late to run again. This causes a discrepancy in the moisture data for the March 1st treatments, but yield and other data indicate the probably true condition.

With the exception noted, for the earlier dates, immediate tillage results in a higher moisture content and in better yields both of grain and of straw. For the late date, the conditions are reversed or practically equal.

SUB-SURFACE PACKING OF FALLOW

A seed bed for cereals should be reasonably firm and the use of some implement to firm the plowed soil has been advocated as a necessary adjunct in dry farming. The sub-surface packer, invented by H. W. Campbell, and known as

Table 11: Total Soil-Moisture, Total Nitrate-Nitrogen, and Yield for Summer-fallow With and Without the Sub-surface Packer (Three Year Average)

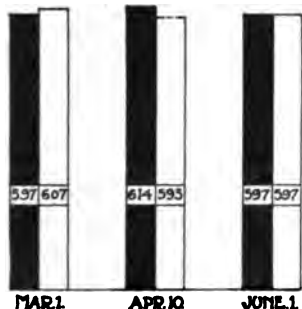
Treatment	Total Soil Moisture	Total Nitrate- Nitrogen	Yield per Acre	
			Grain	Straw
Plowed March 1—				
Packed	597	91.7	9.4	515
Not Packed	607	83.1	8.7	480
Plowed April 10—				
Packed	614	80.2	9.9	515
Not Packed	593	77.0	8.7	485
Plowed June 1—				
Packed	597	73.6	8.9	460
Not Packed	597	72.5	9.0	475
*Plowed June 1—				
Packed	628	80.6	8.7	475
Not Packed	650	81.1	9.8	460

*All plots in this experiment were disked March 1st, the plots of this treatment receiving a second disking on April 10th.

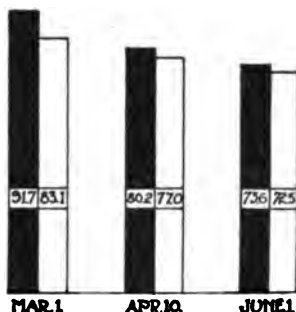
SUBSURFACE PACKING OF FALLOW

SOIL

MOISTURE TONS PER ACRE

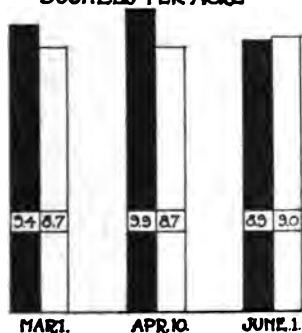


NITRATE NITROGEN POUNDS PER ACRE

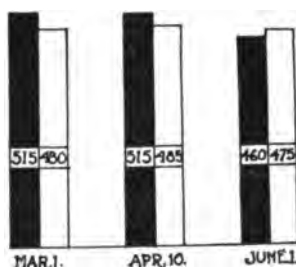


YIELD

GRAIN BUSHELS PER ACRE



STRAW POUNDS PER ACRE



PACKED



NOT PACKED



Figure 11. This graph is based on the data of table 11. It compares packed and unpacked fallow on three dates of spring plowing. On the two early dates packing promotes soil contact, and gives better absorption. Because packing makes necessary more tillage for weed control, the practice is not advisable on light soils because of probable soil blowing. On heavier soils with a better moisture content, the packer is less needed. Its practical use is doubtful. This data is useful, however, in adding emphasis to the advantages of soil contact in moisture absorption. This is discussed on page 40.

the Campbell packer, has been most widely recommended for this purpose. That it has not become of general use indicates at least doubt of its utility. American investigators as a rule have not found the tool useful, Stephens (9), among others, reporting its use as not beneficial in the Oregon section of the Columbia Basin dry farming area.

In this experiment, the packer, weighted to a load of thirty pounds per wheel, was used immediately after the plow, and was followed at once by the spring-tooth harrow.

The data indicate a certain benefit in using the packer on the first two dates. There is a discrepancy in the moisture data of the March 1st plowed treatments, which do not check with yield, but with this exception, the advantage holds for all factors. For the late date, there has been no corresponding benefit.

In practice the utility of the packer is doubtful. More work is required in controlling weeds on soil where the packer has been used, and on light soils the additional tillage tends to develop drifting. It is often suggested that the packer be used to firm the soil and so hold moisture near enough the surface to insure fall seeding without rains. On heavier soil types especially, the use of the packer develops a condition very similar to the plow-sole mentioned on page 45, and unless this condition is corrected by frequent tillage the soil will actually dry more deeply than if the packer is not used. This frequent cultivation tends in turn to unduly fine the surface soil, and there occurs a running together and cementing effect during the winter following the summer of fallow which is very undesirable. As suggested hereafter in the discussion of principles, the benefits of the packer can be secured by other and safer methods. In addition to these factors directly affecting soil condition, there are other considerations, such as costs, which have a bearing on the use of any method or implement and which, in this case, are against the use of the packer.

The chief value of these data is in emphasizing certain principles involved in moisture conservation, which will be developed and discussed hereafter.

DISKING VS. PLOWING FOR FALLOW

Where moisture is a very extreme limiting factor, and yields in no case can be large, it may be necessary to reduce production costs to a minimum. On blowing soils it may also be advisable to leave plant residues on the surface, rather than to plow them under. Under such conditions, if crop return is at all equal, disking might take the place of plowing in preparing the fallow.

DISKING VS. PLOWING FOR FALLOW

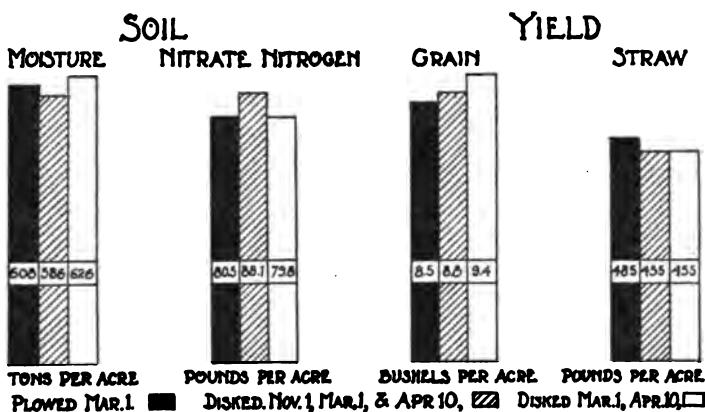


Figure 12. This graph is based on the data of table 12. It compares disking with plowing in preparing the fallow. Plowing has had no advantages over disking during the dry period of this experiment, the latter having the highest average moisture content. This result emphasizes the fact that the detrimental effect of a mulch on absorption is proportional to its depth, see discussion on page 40. "Good farming" does not depend on the use of any particular tool, but rather on developing and maintaining certain soil conditions.

Table 12: Total Soil-Moisture, Total Nitrate-Nitrogen, and Yield for Summer-fallow Prepared by Plowing, by Fall and Spring Disking, and by Spring Disking (Three Year Average)

Treatment	Total Soil Moisture	Total Nitrate-Nitrogen	Yield per Acre	
			Grain	Straw
Disked Nov. 1, Mar. 1, and Apr. 10	586	88.1	8.8	455
Disked Mar. 1 and Apr. 10	626	79.8	9.4	455
Plowed Mar. 1	597	89.0	9.2	475

Through accident, the yield data of the plot given fall and spring disking in preparing the fallow were lost in 1918. For that reason, the yield of this plot for that year has been interpolated. (See Table 13).

During the past three seasons, the average efficiency of disking in preparing the fallow has been equal or slightly superior to that of plowing. This is true in yield, in moisture conservation, and in nitrate development.

MOISTURE CONTROL IN DRY FARMING

Theories of moisture conservation, based on experimental work or experience elsewhere, have not always applied in this area. A study of the foregoing data suggests the reason.

The data shows that varying conditions within and without the soil, variation being due to the influence of date of operation or method of treatment, modify results, and justify differences in practice. (See Depth of Plowing, Table 6). It is, therefore, reasonable to assume the necessity of equal variation in practice under the even wider range in condition found from place to place (See Table 1 and Figure 2), or even from year to year for a given location. (See Tables 2 and 3).

To apply the results of these experiments, and to understand how and why practice should vary, requires a discussion of the principles involved.

SOIL MOISTURE

Moisture conservation is the chief consideration in determining most dry farm tillage operations. The factors concerned are the **absorption** of water and its **retention**.

Moisture enters the soil, both by gravity carrying the free water into the open spaces of the soil, and by capillary movement. Gravity is most active when water is present in large enough quantity to fill the pore spaces of the soil. Under ordinary conditions water is present in dry farming soils only in the form of more or less thin films covering the surface of the soil particles. This film moisture, when present in any quantity greater than the limited amount found in all air-dry soil which limited quantity need not be considered in this

discussion, is known as capillary moisture. This is the most important form of soil moisture from the standpoint of crop use. Capillary moisture moves from a more moist soil to a less moist one, within certain limits, until equilibrium is established (12) (13). Movement may be in any direction. After a rain, when the immediate surface soil is very moist, movement is downward. Later, when evaporation has dried the surface, movement may be upward. A firm soil having many points of contact between soil particles is most favorable to capillary movement of moisture. A loose and open structure, having fewer points of contact, tends to decrease movement. When a soil dries beyond a certain point, movement of moisture from a more moist soil to it is very slow (14). It is a matter of observation that a very dry soil absorbs moisture less readily than one more moist (15).

A combination of all the above factors is the theoretical basis for stirring the soil to prevent the upward movement of soil moisture and its loss by evaporation. This is the theory of the soil mulch. Under conditions of extreme evaporation, soils quickly become very dry at the surface and tend to naturally mulch themselves (14).

Absorption

Where precipitation occurs normally as heavy down-pouring rain, as more gentle rains large in quantity, or as heavy snows with large run-off, the soil surface condition most favorable for moisture absorption is a rough and open one (15). Such a surface holds the water until gravity and capillary movement can carry the largest possible amount of it downward into the soil.

Where precipitation is light, and comes regularly as gentle rains, with very seldom enough water to stand or run on the surface, gravity plays a more unimportant part, and capillary movement, or conductivity, is the important factor in moisture absorption. From the previous discussion of capillary movement, it is clear that a more firm soil condition favors moisture absorption in such a case.

A light, gentle type of rainfall is characteristic, either in

whole or in part, of the dry farming districts of the state of Washington. Evaporation is also active, which makes the rapidity and depth of moisture absorption of very important consideration in saving this moisture for crop use.

Tillage Practices as They Affect Moisture Absorption

The moisture problem of the fallow year begins with the removal of the previous crop. At this season, following the long dry summer, all soils in this district are practically air-dry at the immediate surface, and a cropped soil is at the wilting point to the entire depth of root penetration. The behavior of this dry soil in absorbing and retaining moisture is one of the important factors in determining tillage practice.

Weeds have a very important bearing on the moisture problem, and their control is one of the chief functions of tillage. Burr (15) found, that for Nebraska conditions, harvest disking materially added to the soil moisture supply. Examination of the data in Table 7, or of Figure 7, shows, that under conditions as found in these experiments, dry harvest disking also saved a certain amount of moisture. Soil so disked had a higher moisture content than soil not disked, when both were plowed (September 1st, dry) before other moisture had fallen. However, further study of the same data tells another story. Where such dry disked and undisked soil was allowed to stand until after rains fell before being plowed (November 1st and March 1st), the difference in moisture content favoring the disked soil was first equalized (November 1st plowing) and then reversed (March 1st plowing), the undisked soil being finally the superior in that respect. A study of Table 5, or of Figure 5, where soil dry plowed (September 1st) is compared with similar soil plowed after the fall rains (November 1st and March 1st) tells the same story. In both cases the final moisture content favors the soil left unstirred through the period of moisture absorption. This moisture advantage of the unstirred soil must be due to the dry, loose soil being less efficient as an absorbing agent than is the same dry soil in a more firm, unstirred condition. The absorptive advantage of the unstirred soil is great enough, in the first

case, to more than make up the original saving in moisture due to killing weeds.

Laboratory data, secured by the authors in studies not yet completed, indicate that the depth of penetration of a given amount of moisture is practically equal in the loose and in the compacted soil from the station farm. The difference, in the two cases, lies in the percentage of moisture to soil, which is much higher in the loose soil than in the compacted. This means that moisture films are thicker, immediately after a rain, in a loose surface soil than in an unstirred one. As a result drying winds more easily remove newly fallen moisture from the dry disked or plowed soil than from the same soil in the undisturbed condition (16) (17). Succeeding rains falling on the two soils will be conducted more deeply into the more firm soil because of better moisture content (18), this finally, as a result of collective additions following a number of rains, outstripping the loose soil in total moisture. In field practice, it has frequently been observed in plowing across disked and undisked soil in the fall, that under a disked mulch the soil is dry, while that previously unstirred is moist enough to be in good plowing condition.

The above principle applies in this area for tillage of dry soils on any date. With dry June 1st plowing (See Table 6, or Figure 6) it is operative during the fall and winter succeeding the summer of fallow.

The detrimental affect of the dry mulch on absorption is proportional to the depth of the mulch. This is shown in the generally superior moisture content of the shallow plowing over the deep plowing for all of the dates of dry plowing. There are exceptions to this generalization in the data, but they are not large enough or frequent enough to invalidate the conclusion.

As previously pointed out, the moisture content of the soil has a bearing on its capillary conductivity, and consequently on its efficiency in absorption. As the moisture content decreases and approaches the dry condition, it would be supposed that the soil should react in absorption more nearly like

the dry soil the nearer the approach to the dry state. It is important to understand the limits under which this principle is active. The soil moisture content, in addition to its direct affect on conductivity, also influences other soil physical conditions concerned in conduction. It is, therefore, necessary to consider other variations in soil moisture condition at the time tillage is performed and the ultimate result in absorption in order to arrive at a true understanding of the operation of this fundamental law.

The data on depth of plowing (See Table 6, or Figure 6) give the best comparison of the differences in result from a given operation due to a difference in the soil moisture content at the time the operation was performed. A comparison of the data for the three dates shows that the reaction to depth of plowing has been different for the early date and for the last two dates. On the early date the deep plowing is superior, while for the later dates the superiority rests with the shallow work.

At the early date of plowing, during these experiments, the moisture content of the plow layer has been higher than at any other period, being about 10 to 12 per cent, 12 per cent being close to the maximum capillary capacity of the soil type in a field condition. Evaporation at this season does not as quickly reduce the moisture content in the turned soil, in part due to the fact that rains are still falling in greater or less degree, and the soil settles or naturally firms comparatively more than when plowed under other circumstances.

Cameron and Gallagher (16) have shown that at a certain critical moisture content, which varies with soil type, drying a soil causes a sharp increase in soil volume, this progressive increase in volume with drying continuing until a certain lower moisture content is reached, after which there is no further increase in volume due to decrease in moisture content. As a corollary of this principle, an increase in the moisture content of a soil, when at its greatest volume, causes a decrease in volume within the same limits as occurs the volume increase. The work of these investigators also shows the critical moisture content to be that at which the soil is in best handling

condition, which in the case of the soil under study is about its maximum field capacity.

Applied to field conditions, the above principle means that when the moisture content of the plow layer is near the critical point, slight variations in either direction may give entirely different results in the settling of the turned soil after plowing. In the results of this experiment, at the earliest date of spring plowing, the moisture content has been such that a maximum volume decrease or settling was secured. Because of this settling, or natural firming, the deep plowing and the shallow plowing of this date have been comparatively alike in condition as far as soil contact and its affect on absorption are concerned. The result has been more nearly similar moisture content, other factors tending to favor the deeper work.

At later dates, as the soil in the plow layer becomes more dry, or dries more quickly after being turned, there is a natural tendency in conformity with the above principle to settle less after plowing. By the intermediate date, the soil moisture content has been reduced to a point, about 8 to 9 per cent, where an entirely different result is secured from tillage operations (See Table 6, or Figure 6). The soil is more loose after plowing and later reacts in absorption in the same manner as the more dry soil. The superiority of the shallow plowing of the intermediate date indicates that such is the case.

Rainfall during and succeeding the plowing period has a very important bearing on field practice as influenced by the above outlined principles, and determines the length of time over which the deeper plowing is equal or superior in result to the more shallow work. If later rainfall brings a soil tilled when comparatively dry back to the critical moisture content, the settling effect may practically equal that of a soil turned in a more moist condition. This of course varies with locality and with season, and under conditions more favored than those during the years of this study, might prolong the period well past the date chosen in this case for intermediate plowing. In any event, field operations should be governed, not by date, but by condition as it exists at the specified time, and must be

determined by an intimate knowledge of the individual locality.

The data covering date of plowing (See Table 5, or Figure 5) and wet fall disking previous to spring preparation of fallow (See Table 8, or Figure 8 and Table 12, or Figure 12) indicate that in these experiments nothing has been gained from stirring the soil in the fall. During the four years of this study, fall precipitation has been light, and while the soil was moist enough to plow well when given the wet fall treatments, the moisture content was not at a maximum, corresponding more nearly in condition to the intermediate date of spring plowing. As a result, settling was comparatively slight, and some time elapsed before contact and absorptive condition in the stirred soil equaled that in the unstirred, even though the period following the stirring was that of greatest precipitation. Had rainfall been greater, resulting in a higher moisture content at the date of plowing or disking, and in correspondingly greater settling and better contact, the result might have been different. This latter statement is of course conjecture, but conjecture based on results under a similar condition, and is interesting in that it suggests the necessity of considering condition in its effect on the outcome of a given operation no matter at what date the operation be performed.

In summing up the consideration of absorption in moisture conservation, the importance of one factor, the degree of firmness or soil contact, is apparent in all the data. It is shown in the effect of fall disking, either dry (See Table 7, or Figure 7) or wet (See Table 8, or Figure 8). It is shown in the different results secured from varying the depth of plowing on different dates (See Table 6, or Figure 6). It is shown in the better results from the immediately tilled soils (See Table 10, or Figure 10) and from the sub-surface packed soils (See Table 11, or Figure 11). It is shown in the superior moisture content of the disked fallow over that prepared by plowing (See Table 12, or Figure 12).

The data indicate that for conditions as they have prevailed during the period of these experiments, **absorption is the most important factor in saving moisture for crop use.**

Retention

The theoretical basis of moisture retention in field practice has been the loose soil-mulch. In theory, the mulch is held to break capillary connection between the surface and the underlying soil, so preventing upward moisture movement and consequent loss by evaporation. More recent studies tend to cast some doubt on the relative importance of the mulch in actually saving soil moisture. Call and Sewell (19) hold that, for Kansas conditions, evaporation is not less in the end from a mulched soil than from an unstirred one, and ascribe the beneficial effects of cultivation to killing weeds and to preventing run-off, rather than to retentive qualities in the mulch, and Harris and Jones (10) conclude that for Utah conditions the destruction of weeds is more important than the maintenance of a mulch in conserving moisture.

In this area, the season of moisture conservation is divided into two rather distinct periods, one of precipitation, during which absorption is of paramount importance, and one of comparative drouth during which retention is the major consideration. These two periods over-lap more or less, and the relative importance of the mulch in retention as compared with its detrimental effect on absorption, which has been pointed out, should be understood. In any case, the mulch, created during the dry period, persists into the next period of rainfall, so there can be no sharp definition of function in considering the mulch as such. It must be considered in both phases of its relation to the problem of moisture conservation.

The data covering the retentive affects of the mulch are less conclusive than those covering absorption, yet while probably too limited for definite conclusion, they do indicate that retention has a certain importance, aside from weed control, and should not be entirely disregarded in tillage operations.

During that portion of the absorptive period when plant growth is comparatively inactive, the data show that nothing is gained in moisture conservation by the creation of a mulch. This period extends up to and includes the intermediate date of spring plowing, as shown by the data covering date of

plowing (See Table 5 or Figure 5) and spring disking previous to spring plowing (See Table 9, or Figure 9). After the intermediate date of spring plowing, moisture losses are greater and tillage saves moisture. This is shown in the superior moisture content of the plots disked on the intermediate date and plowed in June as compared with the plots otherwise treated the same without the intermediate disking (See Table 9, or Figure 9). Weed growth, at the time of June plowing, has been very limited on plots disked at the earliest spring date, so moisture differences, in this case, cannot be ascribed wholly to killing weeds.

As additional evidence that the mulch does function in retaining moisture, the moisture advantage of the plots disked twice during the spring and plowed in June (See Table 9, or Figure 9) over those given spring disking only in preparing the fallow (See Table 12, or Figure 12) might be cited.

Previous to the intermediate date of spring plowing, the detrimental affects of the mulch on absorption outweigh or equalize its retentive qualities. After that date, or more properly condition, is passed, retention becomes relatively more important. Considering the problem from a purely moisture conservation standpoint, retention may be promoted and absorption, as it is concerned with the remaining spring rainfall, will not be seriously interfered with by a shallow mulch during this period. The feasibility of creating such a mulch is a matter of management to be decided by the individual operator depending on local conditions.

Later in the season, as temperatures become comparatively high and evaporation acts more rapidly than capillary movement of soil moisture, the soil tends to self mulch. During mid-summer and early fall, the artificial mulch is probably less necessary in retaining moisture.

In general, tillage for weed control must be given at or near the time when the mulch is most efficient as a retentive agent. It seems best, therefore, in practice, to limit all tillage for retention of moisture other than plowing to that necessary to control weeds.

SOIL NITRATE-NITROGEN

Moisture is the chief limiting factor in dry farm crop production, but soil plant food also affects the final result. The influence of tillage operations on plant foods should be at least partially considered before attempting a general application of principles.

The soil plant food element most influenced by tillage is nitrogen. Nitrogen, present in the soil in the form of organic or plant material, is dependent on the activities of certain bacteria, through a process called nitrification, to change it to the nitrate form used by plants. Nitrification under normal field conditions, is most active in the surface six to eight inches. Below the depth of one foot there is very little if any formation of nitrates. The temperature of the soil and the moisture content of the zone in which nitrification takes place are both important in promoting the process (20) (21). Any soil treatment which holds the moisture near the surface for the longest time during the warm period of the year most favors nitrification (22). In a fallowed soil this is best accomplished by maintaining a relatively firm condition with a comparatively shallow mulch.

A study of Figure 5 shows a great similarity in the curve representing total soil moisture and that representing total nitrate-nitrogen. With certain exceptions (See Figure 6), all other data tend to confirm this agreement. This relation is not a direct one, but is due to the fact that moisture conservation and nitrification are, for the particular conditions of this experiment, promoted by a similar soil condition. In this case, proper attention to moisture, the chief limiting factor, also insures the treatment best promoting nitrification.

A careful study of the data shows that, for the dry period of this study, grain yield has been proportional to total moisture and not to nitrate-nitrogen. This indicates that under such conditions, nitrate-nitrogen is not as yet, at least, a limiting factor. Straw yields, however, are affected by nitrate-nitrogen content, which of course indicates greater possibilities in grain yield for a higher nitrate-nitrogen content in a

season or locality of better moisture. This suggests that under better dry farming conditions, nitrate-nitrogen may be a limiting factor in production, and that, in such cases, more attention should be given to tillage as it has a bearing on nitrate development.

A more complete discussion of this factor is reserved for publications intended for use where nitrate-nitrogen does limit production.

INTERPRETATION OF THE DATA IN FARM PRACTICE

It is unwise to make detailed suggestions for applying specific methods under a wide range of conditions, when these suggestions are based on experimental work done under only one set of these conditions. Local variations in soil and climate may materially modify the operation of principles, and the most that can be done with safety is to point out a few of the most important factors involved, leaving the farmer to supply the details for his own particular locality.

The purpose of this bulletin is to develop the principles of moisture conservation concerned in all tillage practice under conditions such as prevail in the area covered. There are always considerations of management or economy which must be borne in mind in applying any principle to farm conditions, and in this case the superiority of any particular method in moisture conservation does not mean that it is economically feasible. The influence of the different variations in these experiments on the result of any given operation has been pointed out, and on this basis it is hoped the reader can interpret the data in terms of **conditions** and **principles**, rather than of methods or systems. If this interpretation be given, these experiments are usable over a much wider range than otherwise.

DRY FARMING IN WASHINGTON UNDER AN EXTREMELY DRY CONDITION

In the more dry districts of this state, farming has very large elements of risk. In favored seasons, yields are good and profits for that particular season are large; but average

yields are comparatively light, and without careful management, operation costs during poor years may be enough larger than income to more than balance the profits of better ones. For that reason, the expense of all operations must be kept at a minimum.

It is hoped the discussions of this bulletin will aid in understanding what is necessary tillage, and how the desired result may be secured with a minimum of labor and expense.

The data of the experiments show that a firm condition, or a modified firm condition, of the soil is most favorable in saving moisture. The degree and kind of firm condition desired depends on the period of the year.

In the fall, soil moisture is low in stubble ground, and little can be lost by evaporation. Weeds may take a certain amount, but not enough to off-set later losses from poor absorption if the soil is stirred while dry. Under ordinary conditions, **do not fall disk or plow, either wet or dry.**

In the spring, the moisture content of the surface soil is largest in amount and losses by evaporation are proportionately greater than at any other time. Tillage at this time, by killing weeds and by creating a surface mulch, lessens initial moisture losses. Because the soil is very moist, it settles and even after being stirred absorbs moisture comparatively well. On the light soil types prevailing in this region, it is very desirable that the surface be as cloddy as possible. Such a cloddy surface does not blow as readily as a more pulverized one, and the soil physical condition following rains is also better. Early tillage is best for creating the cloddy condition. **Prepare fallow as early in the spring as possible.**

Only a part of early tillage (plowing, disking, etc.) can be early enough to catch the soil when it is most moist. As the season progresses and the soil moisture approaches the lower limits at which the soil still plows well, tillage should be more shallow. **The lighter the annual rainfall, the more shallow should be the average depth of plowing or other tillage.**

In practice, continued shallow plowing results in the formation of a plow-sole just under the turned soil. Such a plow-

sole can be broken up by varying the depth of plowing. **Deep plowing is equal or superior to shallow plowing only in early spring.**

Soil blowing may modify tillage practice. The problem is not within the scope of this bulletin, yet brief attention should be given the question as influenced by the fundamentals of dry farming. The use of any method, which controls soil blowing, is good if the method also conforms to the principles of moisture conservation. The seriousness of the problem may sometimes over-shadow all other considerations, but moisture is still the factor which limits production after the blowing is stopped, and a method which merely controls the blowing without conserving moisture has not solved the problem.

Control of weeds on the fallow is essential. Tillage for this purpose should be the only tillage ever practiced when the soil is dry.

In determining tillage methods a careful study should be made of local conditions. Learn how these conditions affect absorption and retention of moisture. On this basis, determine how and when the least labor will produce the desired result. Reduce all tillage to the necessary minimum.

DRY FARMING IN WASHINGTON UNDER MORE FAVORED CONDITIONS

The same general principles apply as under the more arid conditions. Differences in soil type and rainfall (See Figure 2), however, give somewhat different results from tillage. Because of the more abundant moisture supply, practice has a wider range for variation without equally pronounced detrimental effects. In other words, operations that are distinctly detrimental under drier conditions may be only slightly so or not at all with greater rainfall.

A dry surface mulch acts exactly as it does under the more arid condition, so long as rains are not of sufficient volume to wet through the mulch. However, a greater rainfall more quickly penetrates the mulch and its detrimental affect is less-

ened and not so prolonged. Under the greater rainfall both the absolute and the proportionate inhibitory absorptive effect are less than in the drier districts.

The volume of precipitation and soil type have an important bearing in determining the advisability of fall tillage under the more favored conditions. As pointed out in the discussion of fall plowing on page 40, the moisture content of the soil determines very largely the physical effect of plowing, whether or not the soil settles, and its condition as affecting moisture absorption. If fall moisture is abundant, any soil will be in better condition for absorption following tillage, and fall plowing may be practiced with proportionately better results. With better rainfall, soil type is also usually heavier and the soil pulverizes less when plowed dry. This results in a condition not unfavorable for absorbing run-off from the melting snows. Any or all of these factors may be operative to the extent that the choice between fall and early spring plowing becomes one of management in getting all plowing done at the most favorable period.

There does not, however, appear to be a valid reason for either fall disking or plowing of fallow, provided the work can be done at the proper time in the spring. It may be argued that stubble and straw residues should be turned under in the fall, but the advantages of this are doubtful. Standing stubble prevents the blowing of snow from fields and checks the evaporative effect of winds. A heavy stubble is undoubtedly more efficient in saving moisture than is the stirred soil. There are exceptions to this statement, but it will hold true in the great majority of cases in this area. If stubble and straw must be worked into the soil before plowing, spring disking is as effective as is the fall work, and there are no possible detrimental results from stirring the soil at this time. However, as suggested above, the question of fall tillage is a matter of condition and of management, and must be decided by each individual farmer for himself each year, his decision being based on these factors.

When for any reason, spring plowing is to be delayed until after volunteer grain and weeds will have made considerable

growth, the soil should be disked early enough to prevent such growth. Experimental evidence shows that early disk-ing and late plowing is a good system in conserving moisture, and it works well from a management standpoint in growing spring wheat.

For winter wheat very early spring plowing is preferable. A more settled soil condition is desirable than for spring wheat. This more firm soil holds moisture nearer the surface, and comparatively light fall rains allow seeding. Early spring plowing, at a time when the moisture content of the soil is high, favors the development of this condition with a minimum of subsequent tillage.

As suggested in outlining the limits for applying the conclusions of this bulletin, there are conditions in this state where the principal benefit of the summer-fallow is due to its effect on nitrification. The greater the rainfall, the more attention should be paid to this factor. In such cases, immediate tillage after the plow is desirable. Heavier soil types, in particular, do not break up as completely in plowing as is most desirable, and the additional tillage is necessary to work down inequalities. Without this stirring, such soils do not properly settle and tend to dry out more or less irregularly through the plow-layer. This checks nitrification. Immediate tillage after the plow is not always advisable, and local conditions may overbalance some of its advantages, yet as a general rule, the practice is desirable under the better conditions.

Weed control on the fallow is just as essential under more favored as under less favored conditions. Not only do weeds remove moisture, but they use the nitrates so necessary in producing the crop.

SUMMARY

1. The discussion of principles and conclusions are based on conditions as they exist in the state of Washington under a rainfall of 15 inches and less.

2. Under these conditions, moisture is the **direct** limiting factor in production, and the summer-fallow system of tillage for the conservation of moisture is necessary.

3. Moisture conservation depends on the **absorption** and the **retention** of precipitation.

4. Tillage operations should be planned to control absorption and retention in so far as this is possible.

5. In this district the regulation of absorption is the most important consideration in determining tillage methods.

6. With a light, intermittent rainfall, followed by drying winds, a comparatively firm soil condition most favors absorption and a loose soil condition hinders the process.

7. Under conditions where a loose soil is unfavorable in moisture absorption the detrimental affect is in direct proportion to the depth of the loose soil.

8. At a moisture content near the field capillary capacity for the given soil type, a soil tends to settle, or naturally refirm itself, to the greatest degree after stirring. Under such conditions, plowing or other tillage may be deeper without an equally detrimental affect on absorption.

9. At a lower moisture content, a soil tends to remain in a more loose condition after being stirred. As the moisture content of the plow-layer diminishes, plowing or other tillage should be more shallow, in order to avoid the detrimental affect of the loose soil on absorption.

10. The lower the average annual rainfall the more shallow should be the average depth of plowing. In general, depth of plowing should decrease with the advance of the spring season.

11. Retention of moisture is best accomplished by early spring preparation of the fallow and the control of weeds.

12. Variations in soil type and in the average annual rainfall give varying results from any specified operation or system. Each farmer should possess an intimate knowledge of local conditions in order to regulate operations properly and to apply principles accurately and in accord with best economy.

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APPENDIX

Table 13: Moisture, Nitrate-Nitrogen and Yield Data of One-twentieth Acre Plots in the Tillage for Summer-Fallow Experiments for the Years 1918, 1919 and 1920. Adams Branch Experiment Station

Tillage Treatment	Year	Moisture Per Acre		Nitrate Nitrogen Per Acre			Yield Per Acre		
		Spring	Fall	Spring	Fall	Straw	Grain	Bushels	Pounds
Plowed September 1st (Dry) 4 inches	1918	367	169	32.8	...	...	...	3.8	190
	1919	578	210	28.1	11.5	...	...	9.3	600
	1920	550	225	133.6	71.6	...	...	7.2	280
Plowed September 1st (Dry) 6 inches	1918	391	196	30.8	...	...	...	4.0	210
	1919	547	210	40.3	6.4	...	...	8.5	540
	1920	556	232	140.1	81.8	...	...	7.0	300
Plowed November 1st (Wet) 4 inches	1918	371	180	43.4	...	...	...	4.2	240
	1919	613	217	43.4	22.9	...	...	10.5	640
	1920	545	228	110.1	77.2	...	...	7.9	320
Plowed November 1st (Wet) 6 inches	1918	457	229	37.0	...	...	...	4.0	280
	1919	629	220	59.0	13.0	...	...	8.7	510
	1920	540	228	136.5	83.3	...	...	7.5	360
Disked Immediately After Harvest and Plowed (Dry) September 1st—6 inches	1918	490	229	18.7	...	...	...	3.8	180
	1919	604	215	42.0	7.6	...	...	9.7	570
	1920	538	225	128.4	58.1	...	...	6.8	295
Disked Immediately After Harvest and Plowed (Wet) November 1st—6 inches	1918	446	211	32.4	...	...	...	4.0	240
	1919	626	217	37.5	8.2	...	...	9.7	610
	1920	518	253	150.4	76.7	...	...	7.1	300
Disked Immediately After Harvest and Plowed March 1st—6 inches	1918	521	240	29.9	...	...	...	5.6	320
	1919	637	232	59.2	7.6	...	...	12.2	700
	1920	550	232	135.6	82.7	...	...	8.3	380

Table 18—(continued)

Tillage Treatment	Year	Moisture Per Acre		Nitrate Nitrogen Per Acre		Yield Per Acre	
		Spring	Fall	Spring	Fall	Grain	Straw
		Tons	Tons	Pounds	Pounds	Bushels	Pounds
Disked Late Fall (Wet) Plowed March 1st 4 inches	1918	509	228	40.4	...	5.2	280
	1919	677	225	47.2	19.1	10.7	690
	1920	587	214	137.7	64.9	7.8	325
Disked Late Fall (Wet) Plowed March 1st 6 inches	1918	548	261	40.7	...	5.5	270
	1919	667	235	52.8	14.0	11.7	860
	1920	613	237	140.5	83.9	8.0	300
Disked Late Fall (Wet) Plowed March 1st 8 inches	1918	536	229	31.1	...	6.2	360
	1919	685	235	57.3	34.0	12.7	800
	1920	604	228	158.2	92.7	7.9	370
Disked Late Fall (Wet) Plowed April 10th 4 inches	1918	549	236	48.7	...	6.0	360
	1919	666	237	48.8	19.1	11.7	600
	1920	608	232	121.8	70.3	8.1	310
Disked Late Fall (Wet) Plowed April 10th 6 inches	1918	503	229	43.4	...	5.7	380
	1919	628	220	56.5	24.2	11.3	580
	1920	575	238	138.7	99.5	6.8	250
Disked Late Fall (Wet) Plowed April 10th 8 inches	1919	504	218	35.5	...	6.1	430
	1919	635	225	39.5	16.6	11.7	600
	1920	568	235	121.9	75.1	7.7	300
Disked Late Fall (Wet) Plowed June 1st 4 inches	1918	487	234	48.7	...	5.8	370
	1919	583	210	35.2	12.7	10.0	480
	1920	545	222	89.2	71.7	6.2	270

Table 13—(continued)

Tillage Treatment	Year	Moisture Per Acre		Nitrate Nitrogen Per Acre			Yield Per Acre	
		Spring	Fall	Spring	Fall	Grain	Straw	Pounds
Disked Late Fall (Wet) Plowed June 1st 6 inches	1918	508	223	34.8	...	5.9		380
	1919	536	200	33.6	15.3	11.0		560
	1920	543	239	33.6	71.2	6.4		280
Disked Late Fall (Wet) Plowed June 1st 8 inches	1918	508	212	44.2	...	6.3		380
	1919	541	202	31.4	10.2	9.3		480
	1920	575	225	131.7	65.3	6.2		320
Disked Late Fall (Wet) Disked March 10th and April 10th—No Plowing	1918	486	212	39.9	...	*6.3		*385
	1919	677	227	43.4	10.2	11.3		560
	1920	596	260	181.0	67.5	8.8		420
Disked March 1st and April 10—No Plowing	1918	543	245	46.2	...	7.2		380
	1920	734	235	44.0	8.9	11.2		540
	1920	602	222	149.1	51.8	9.8		440
Disked Late Fall (Wet) Disked March 1st, Plowed March 1st—6 inches	1918	559	250	48.7	...	6.1		430
	1919	703	230	55.4	...	11.2		630
	1920	558	253	145.3	67.5	8.7		380
Disked Late Fall (Wet) Disked March 1st, Plowed April 10th—6 inches	1918	528	251	49.8	...	5.9		430
	1919	668	230	45.6	19.1	12.0		640
	1920	583	245	135.5	78.2	8.1		380
Disked Late Fall (Wet) Disked March 1st, Plowed June 1st—6 inches	1918	540	234	43.2	...	5.8		400
	1919	691	260	38.9	15.3	13.3		640
	1920	561	245	135.4	63.0	8.0		390

*Through accident the data for this treatment was lost, the data here given being interpolated.

Table 18—(continued)

Tillage Treatment	Year	Moisture Per Acre		Nitrate Nitrogen Per Acre		Yield Per Acre	
		Spring	Fall	Spring	Fall	Grain	Straw
Disked Late Fall (Wet) Disked March 1st, Disked April 10th, Plowed June 1st	1918	Tons 611	Tons 262	Pounds 50.5	Pounds ...	Bushels 5.9	Pounds 400
	1919	755	270	54.5	10.2	14.3	700
	1920	584	242	138.4	102.0	9.2	375
Disked Late Fall (Wet), Disked March 1st, Plowed March 1st, Packed	1918	555	261	63.5	...	6.3	380
	1919	647	215	55.9	12.0	12.7	700
	1920	588	239	155.6	64.3	9.1	460
Disked Late Fall (Wet), Disked March 1st, Plowed April 10th, Packed	1918	572	262	48.5	...	6.3	380
	1919	666	227	34.1	17.8	14.3	720
	1920	603	242	158.0	65.9	9.0	450
Disked Late Fall (Wet), Disked March 1st, Plowed June 1st, Packed	1918	550	246	49.6	...	5.2	290
	1919	654	235	40.5	11.5	13.3	760
	1920	587	222	130.6	85.4	8.3	335
Disked Late Fall (Wet), Disked March 1st, Disked April 10th, Plowed June 1st, Packed	1918	514	240	50.8	...	6.2	390
	1919	766	235	39.8	11.5	11.3	680
	1920	604	235	151.2	74.9	8.7	350
Plowed March 1st—6 inches	1918	497	229	45.2	...	6.2	360
	1919	638	232	68.5	22.4	12.3	790
	1920	616	237	138.0	65.8	9.8	570
Plowed April 10th—6 inches	1918	561	245	30.6	...	6.0	380
	1919	682	250	49.3	8.9	14.2	700
	1920	588	244	127.7	82.6	9.2	415

Table 13—(continued)

Tillage Treatment	Year	Moisture		Nitrate Nitrogen		Yield	
		Per Acre		Per Acre		Per Acre	
		Spring	Fall	Spring	Fall	Grain	Straw
Plowed June 1st—6 inches	1918	Tons 474	Tons 208	Pounds 27.9	Pounds ...	Bushels 5.3	Pounds 330
	1919	602	200	26.4	11.5	11.3	500
	1920	495	258	102.7	58.7	5.0	250
Plowed March 1st—6 inches Delayed Tillage only	1918	572	207	29.3	...	5.8	310
	1919	663	240	61.8	8.2	13.2	730
	1920	563	263	155.6	122.9	8.3	420
Plowed April 10th—6 inches Delayed Tillage only	1918	545	239	35.5	...	5.6	330
	1919	653	232	46.4	15.3	12.7	680
	1920	573	263	135.0	53.6	9.5	385
Plowed June 1st—6 inches Delayed Tillage only	1918	503	240	34.4	...	5.6	330
	1919	596	210	28.2	7.6	9.3	520
	1920	521	265	110.1	60.2	6.4	375

Note. The nitrate-nitrogen data for 1920 are all too high. In clearing the filtrate for the nitrate determination a supply of CaO was used which had been on hand for some time. This had apparently become largely changed to the carbonate form, and as a result certain compounds were present in the colorimetric solutions which increased the readings much above the true figures. This fact was not checked until too late to recheck. However, other determinations indicate that all of the data are proportionately in error and results are comparative as between different tillage treatments.

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STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISION OF CHEMISTRY

An Investigation of Sulfur as a Plant Food

By

GEO. A. OLSON and J. L. ST. JOHN

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AN INVESTIGATION OF SULFUR AS A PLANT FOOD*

INTRODUCTION

Sulfur and land plaster have been regarded as more or less important plant food for many years but definite information as to their function as plant food material has been very incomplete.

In 1909, therefore, the Washington Agricultural Experiment Station undertook to determine whether or not Washington soils are deficient in sulfur, what function sulfur in the soil plays in plant nutrition and whether or not much of the beneficial effect of land plaster as a fertilizer is due to its sulfur rather than its calcium content. Since then, this study has been conducted with more or less regularity at the Experiment Station at Pullman and in cooperation with farmers in the neighborhood of Pullman. This paper deals with the results obtained in these studies.

In connection with this work, an improved method for estimating the total sulfur in both soil and plant material has been devised. The sulfur content of some of the virgin and cultivated soils of Eastern Washington and various forms of plant material has been determined. Various crops have been grown in the field and under greenhouse conditions using sulfur in a comparative way. A study of the effect of sulfur containing chemicals on the solubility of the mineral plant food in the soil has also received attention. The results of these investigations are presented in this bulletin.

An historical review dealing with sulfur and sulfur compounds as plant food and the effect of these substances on the solubility of soil minerals, the amount of sulfur brought to the earth by means of rain, the sulfate content of drainage water and many other related subjects are summarized.

*The authors here wish to acknowledge the helpful assistance of W. L. Hadlock, C. K. McWilliams, A. L. Sherman and A. E. Craner in the laboratory work in connection with this investigation

HISTORICAL

Sulfur Content of Crops: On the basis of the sulfur analysis made by Wolf, the sulfur content and requirement of plants was considered for years to be very low. As is well known, these original sulfur analyses were made on the ash of the plants. It has been shown by various investigators, among whom are Hart and Peterson (115), Shedd (207), and Ames and Boltz (2), working with the Osborne sodium peroxide fusion method or other methods, that the sulfur content of plants is much higher than the original analyses indicated. Sulfur is usually considered to be present in plants in one or both of two forms, organic and sulfate sulfur. The amount of sulfate sulfur present in the plant seems to vary with soil treatment. Shedd (205) found that sulfur treatment increased the sulfate content of plants, as well as the total sulfur content. In clover and alfalfa, the increased sulfur content was practically all in the form of sulfate. Reimer and Tartar (194) noted that alfalfa from sulfur-treated plots contained a higher per cent of sulfur than the alfalfa from untreated plots and it also contained sulfates. The amount of sulfur per ton of alfalfa did not exceed 4.54 pounds; they concluded that 2.54 pounds per ton is too low and that 3.30 pounds per ton is sufficient for a good crop of alfalfa. Peterson (184) shows that seeds contain but traces of sulfates or more probably, none at all. Shedd (205) found an increase of organic sulfur in soybeans from the use of ammonium sulfate as a fertilizer. Peterson (184) found more organic sulfur in clover, rape, and radishes, where sulfur was present in the fertilizer used. Ames and Boltz (2) report increase of organic sulfur in rape where sulfates were applied to the soil.

In a great many localities, phosphorus seems to be the limiting element in crop production. When we compare the amount of sulfur and phosphorus in plants, we find that in some cases there is at least as much of sulfur as of phosphorus. Ames and Boltz (2) state that the cruciferae contain an amount of sulfur which exceeds that of phosphorus, and that ordinarily cereals contain approximately half as

much sulfur as phosphorus. Hart and Peterson (115), Shedd (207 and 208), Brown and Kellogg (37) and Swanson and Miller (224) all show that many cultivated plants contain a larger amount of sulfur than of phosphorus. Storers (219) quotes analysis by Boussingault, showing a greater amount of phosphorus in clover produced on land manured with gypsum than in clover produced without use of this fertilizer. Occasionally, the application of sulfur fertilizers also seems to have an effect on the amount of nitrogen and other elements in plants. Reimer and Tartar (194) noted that alfalfa from sulfur-fertilized plots contained a higher per cent of nitrogen. Shedd (205) reports an increase in protein content of soybeans from ammonium sulfate fertilizer. Ames and Boltz (2) found larger protein content in rape when sulfates were used in the fertilizer. Lipman (151) found that gypsum often increased the total nitrogen of the crop removed. On the other hand, Lipman, Blair, McLean, and Wilkins (149) report that gypsum did not greatly affect the nitrogen content of soybeans or buckwheat. Shedd (205) also reports that soybeans did not show increased protein with increased sulfur. Singh (211) has recently found that gypsum, on Iowa silt loam, did not affect the nitrogen and potassium content of leguminous crops, except with red clover which showed an enormous increase of potassium.

Sulfur Content of Soils: In regard to the sulfur content of soils, a rather wide variation is found. Clarke (51) states that the earth's crust contains an average of .11 per cent of sulfur. Robinson (197) gives analysis of various types of soil from different regions showing an extreme variation of 160 pounds to 2600 pounds of sulfur per acre in the surface soil. In an earlier publication, Robinson (196) showed the sulfur content of various types of soil to vary from 240 pounds to 3120 pounds per acre in the surface soil, the average being 1040 pounds. Reimer and Tartar (194) found that from 300 to 760 pounds of sulfur per acre appeared in the surface soil. Brown and Kellogg (37) showed the sulfur content of the surface soil of representative Iowa soil types to run from 719 to 938 pounds per acre. According to Ames

and Boltz (2) there were 412 to 800 pounds of sulfur per acre in Ohio uncultivated soils and slightly less in the corresponding cultivated soils. Conner (Proceedings Indiana Academy of Science 1914) found cropped soils to contain the same amount of sulfur as virgin soils (480 pounds). Swanson and Miller (224) give the per cent of sulfur in two virgin soils as 0.044 and 0.062 and in the corresponding cropped soils as 0.027 and 0.036 per cent, thus showing a loss of 38.5 and 41.5 per cent of sulfur respectively from the cropped soil. In a set of virgin soils the sulfur content varied from 0.036 to 0.062 per cent, the average being 0.046 per cent. They give the average for subsurface soils as 0.044 per cent and 0.034 per cent for subsoil. In a cropped soil, the sulfur in the surface soils varied from 0.017 to 0.036 per cent, averaging 0.027; the subsurface average was 0.022 and the subsoil average was 0.026 per cent.

Upon comparing the sulfur and phosphorus content of the soil, Hart and Peterson (115), Shedd (207 and 208), Brown and Kellogg (37), Swanson and Miller (224), and Ames and Boltz (2) all found the soil to contain less sulfur than phosphorus.

Loss in Drainage: Although the loss of phosphorus in drainage water is very small as noted by Lyon and Bizzell (158) and others, as well as by one of the authors in unpublished results obtained at the Illinois Experiment Station, the amount of sulfur lost is quite appreciable and in some cases, seems to be large. From the Rothamsted data, Stewart (215) estimates a loss of from 20 to 80 pounds of sulfur per acre annually. He also states that European estimates are from 8 to 270 pounds depending on treatment. The loss in Arkansas is estimated at 6 pounds per acre. Lyon and Bizzell (158) report that the sulfur content of drainage water from unplanted soils was about equal to the sulfur content of the crop and drainage from the planted soil. They also report that the sulfate sulfur in drainage was three to six times as great as in the crops. They summarize some of the results of other investigators and find that from uncropped soils the loss of sulfur varies from 8 to 208 pounds per acre per year.

These extremes are both results from German sources. From cropped soils the loss varied from 26 to 281 pounds. These reports indicate that cropping seemed to conserve sulfur. Swanson and Miller (224) conclude that " * * the loss in sulfur due to the amount taken up by the crops is insignificant when compared with the total amount which has disappeared from the soil." They believe that sulfonation has been in excess of the needs of the crops and the sulfates produced have been leached out of the ground. Hart and Peterson (115) calculated, from Wisconsin and Rothamsted data, that the loss of sulfur in drainage is three times the amount brought from the atmosphere. Hall (107) shows that the average amount of sulfur leached from the soil amounts to three times the amount added by rainfall. MacIntire, Willis and Holding (159) determined the loss of sulfur in drainage from lysimeters receiving various calcium and magnesium fertilizers and found a loss of from 13 to 64 pounds of sulfur per acre, with an eight ton application of the salts.

Sulfur Supplied by Rain: Steward (215) presents data showing the average precipitation of sulfur in rainfall over a period of seven years to be 45.1 pounds, per acre, annually. A three years average from another gage shows 40.8 pounds per year. MacIntire, Willis and Holding (159) report a three years average of 49.6 pounds of sulfur, per acre, in Knoxville, Tennessee, rains. Hall (107) and Hart and Peterson (115) have measured about 7 pounds of sulfur in the annual precipitation. Ames and Boltz (2) state that Kossovich found that the quantity of sulfur, per acre basis, contained in the rain, varied from 9 pounds in the country districts to 72 pounds in or near towns and cities. Ames and Boltz think that the rains of the United States carry an average of 6 to 7 pounds of sulfur per acre.

Sulfur Requirement: Numerous writers have commented on the need of sulfur fertilizers. Hart and Tottingham (116) state that " * * * minimum requirements for maximum plant development have never been established for any of the essential elements." They " * * * suggest that informa-

tion as to whether sulfur is a limiting factor for plant growth in any soil may probably be obtained by testing for the presence of sulfates in the plants grown on that soil." Their presence would indicate that there was a sufficient supply for all constructive purposes in which sulfur is involved. Tottingham and Hart (230) believe that adequate consideration of the use of sulfur must recognize its tendency to deplete the stock of calcium, phosphorus and other soil constituents. Reimer and Tartar (194) have obtained large increases in the yield of alfalfa by the use of sulfur fertilizers alone but state " * * * that eventually, at least one other element, phosphorus, must be added to these soils, and this in the near future." Hopkins (126) thinks that the high sulfur content of plants does not represent their needs, but merely shows the superabundance of sulfates in the soil water, with an extraordinary consumption by the plant as a result. Stewart (215) concludes that sulfur fertilizers are not needed as the supply from the rainfall is sufficient. Brown and Kellogg (37) conclude that commercial sulfur-containing fertilizers must be supplied to the soil, as grain farming does not return sulfur to the soil and manure cannot be obtained in sufficient amounts to maintain the sulfur supply. They believe that when phosphorus is also needed in the soil, acid phosphate would probably be the logical fertilizer to use.

Effect on Yield. The results of fertilization with sulfur and sulfur compounds have been reported by a large number of investigators. Tottingham and Hart (230) showed that yields of oats from soil cultures were greater where sulfur had been added. Shedd (205) noted that, depending on the crop and soil, sulfur gave increased production, or no effect, or injury. There was a preponderance of gains from sulfur application but these were usually small. Sherbakoff (209) obtained increased yields of potatoes with 100 pounds of sulfur per acre, but 300 pounds or more seemed to be injurious. McConnell (161) found that sulfur gave good results with turnips. Bernhard (11) found that sulfur (44 pounds per 600 square yards) showed marked benefit on potatoes and mangolds. Feilitzen (81) found that four out of five varieties

of potatoes yielded more with the inclusion of 351 pounds of sulfur per acre in the normal fertilizers. Sabasnikov (201) applied sulfur (10 g. per square meter) to clay soil (.082% sulfur tri-oxide) and produced decided increased yields of barley and rye. Chauzit (50) found that application of sulfur increased the yield of grapes from 1.93 to 20.0 per cent, and when it was used with other fertilizers, the yield increased from 9 to 36 per cent. The best results, however, were obtained when sulfur was used in connection with organic matter. Fellers (83) added sulfur, 200 pounds per acre, to an acid sassafras sandy loam soil of low productivity and slightly increased the yield of soybeans. Boullanger (23) and Boullanger and Dugardin (24) increased the crop yields by applications of sulfur. The increases obtained were much less pronounced in sterilized soils. Demolon (64) obtained similar results. Ames and Boltz (2) obtained increased yields with applications of sulfur on certain crops. Chanerin and Desriot (47-48-49) by applying sulfur at the rate of 223 to 446 pounds to the acre, obtained increased potato and beet crops. Boullanger compared sulfur and sulfates on garden crops and obtained increases in most cases. The plots treated with sulfur gave the best results. Vercier (237) and Liechti (138) reported favorable results from the use of sulfur as a fertilizer. Urban (235) secured good results with sugar beets by application of sulfur. Feilitzen secured good results with potatoes, Bernhard (11) with potatoes and mangolds, Mangien (166) with turnips and beets, Tottingham with rape and radishes, and Ames and Boltz (2) with clover by using sulfur as a fertilizer. According to Shedd (207), certain forms of sulfur had no effect on yield. Trischler (233) obtained but slightly increased yields of mangolds. Voelcker (242) found sulfur to be without effect on mustard, rape and clover. Bossinelli (21) thought sulfur of very doubtful value. Pfeiffer and Blanck (187) found that sulfur applied at the rate of 267 and 524 pounds per acre did not increase yield of oats. Pfeiffer and Simmermacker (188) obtained doubtful results with beets. Injury to crops has been noted by Demolon (64), Giannitto (91), Janicand (130) and

Hart and Tottingham (116) from the use of sulfur. Wheeler, Hartwell and Moore (248) noted injury to cereals following potatoes unless lime was used with sulfur. Sherbakoff (210) obtained a poor stand of clover by using 900 pounds of sulfur unless lime was added. Feilitzen (82) and Lint (140) report similar results. Janicand (130) found in pot experiments that applications of sulfur increased the yield of tomatoes. In combination with ammonium sulfate or complete fertilizer sulfur increased the yield of tomatoes. Halsted (112) found that 720 pounds of sulfur per acre reduced the yield of the succeeding crop of potatoes nearly one-half. Wheeler, Hartwell and Moore (248) found marked reduction in yields of oats and millet. Sherbakoff (210) found that 900 pounds of sulfur gave a poor stand of clover which was improved by supplementation with lime or commercial fertilizer. On soil rich in humus there was practically no injury. With larger amounts of sulfur no plant growth was obtained. Four hundred and fifty pounds of sulfur per acre showed much less injurious effect.

Vermorel and Danthony (239), in a series of pot experiments, applied sulfur at the rate of 44.6 to 89.2 pounds per acre, and obtained increases only where organic matter was present. Chauzit (50) obtained the best results with grapes where sulfur was used in conjunction with a fertilizer high in organic matter. Vermorel shows that manure enhanced the benefits of sulfur. Zolla (254) asserts that the effect of sulfur varies as the organic matter, producing a marked increase in the presence of a high amount of organic matter. Sherbakoff (210) found the injurious after effects of sulfur to be greatest on part of the field containing a very low amount of humus. Sabasnikov (201) observed that sulfur gives the best results when applied to a fertile soil.

Giannitto (91) obtained an increase in yield of potatoes when 400 pounds of sulfur, per acre, were applied with other fertilizers and a decrease where sulfur was applied alone. Chauzit (50) found the same variation with grapes. McConnell (161) and Janicand (130) obtained similar results.

Reimer (194) noted that in ranch experiments, gypsum, sulfur, superphosphate and iron sulfate all gave greatly increased yields frequently being double the check plot yields. The stand was thicker, freer from weeds, and the plants were larger and much darker green in color. Rock phosphate and lime gave no increase of yield. Shedd (207) asserted that gypsum added to nitrogen, potassium and phosphorus gave a decided increase of tobacco. Various sulfur fertilizers gave increased yields of soybeans and turnips, some fertilizers gave increased yields of mustard and in some cases gave increased yields of radishes and alfalfa. Tottingham and Hart (230) found that gypsum was superior to sulfur when used both with and without lime. Singh (211) asserted that an application of 1000 pounds of gypsum increased the yield of red clover in a silt loam soil, and that 100 and 500 pounds had no effect on other legumes or wheat. Pitz (189) states that calcium sulfate, in small amounts, increases the yield of red clover. Sulfur gave very slight increases. Batten (9) reported an increase of about 25 per cent in the yield of peanuts from the application of gypsum. Thorne, Williams, and Ames (228) obtained increases in the yield of corn, wheat and hay by use of gypsum on manure. Ames and Boltz (2) state that Takeuchi found as a rule that gypsum decreased the yield when used with acid fertilizers, and increased the yield when used in connection with alkaline fertilizers. Gypsum added to acid phosphate, potassium chloride, sodium nitrate, calcium carbonate, and potassium sulfate gave increases in the weight of soybean hay in both pot and field experimental plots. Greaves and Carter (99) and Kalayana (133) obtained better yields of rice with better color by the use of gypsum. Lipman (149), in pot experiments with soybeans, showed that there was little difference in the crop yield or nitrogen content of the plants fertilized with various amounts of calcium sulfate in a loam soil fairly rich in plant food. Calcium sulfate gave a lower percentage of nitrogen in plants than other fertilizers did. In another place (149) he showed that gypsum had little or no effect on yield or protein content of soybeans. Fellers (83) stated that calcium sulfate exerted

little influence on the yield of soybeans until 600 pounds per acre had been applied. Lipman, Blair, McLean and Wilkins (149) found that calcium sulfate did not greatly affect the yield of soybeans. Gardner, Nolls and Baker (89) found that gypsum did not increase the yield (160 pounds per acre per year). Stewart (215) has presented results showing that potassium sulfate has not increased the yield of corn, oats, wheat, clover, soybeans or alfalfa in a livestock or grain system of farming.

Miller (171) obtained an increased growth of red clover, rape and oats in greenhouse experiments by addition of sodium sulfate, calcium sulfate and sulfur. It is concluded that the sulfur acted directly as a plant food. Lipman and Gericke (143) believe that the superiority of ammonium sulfate over other forms of ammonium fertilizers for barley on blow sand is due to its sulfur content. Nedokuchaev (174) states that ammonium sulfate applied to quartz and loam increased the yield of oats, flax, and potatoes. Jones and Shive (132) obtained better yields of wheat with ferrous sulfate in nutrient solution than with ferric phosphate.

Hart and Tottingham (116) reported stimulation to seed production in both barley and oats by sulfates on silt loam. Calcium sulfate increased the clover dry matter about 23 per cent. It gave the greatest increase with rape when used with complete fertilizers. Sulfur was generally harmful even in the presence of a generous supply of calcium carbonate. Brown and Johnson found that sulfate had no effect on the yield on black loam rich in sulfur and poor in phosphorus. Ames and Boltz (2) found that the crops grown in the field tests reported, do not give conclusive evidence that the addition of sulfur in the form of potassium sulfate to a soil, having a naturally low sulfur content, has increased the yields of general farm crops to any appreciable extent. Griffiths (102) obtained much greater yields of beans, turnips, mangels, potatoes, hay and grass by the use of iron sulfate, but the yield of wheat and other grains was not increased. More phosphorus was contained in bean plants and other crops from manured plots. Hill (123) and Brooks (31) obtained larger

yields of wheat and soybeans by use of iron sulfate. Lipman (151) obtained an increase in dry matter with corn, oats, wheat and timothy, using 50, 100, and 200 pounds ferrous sulfate per acre. Dymond, Hughes and Jupe (74) demonstrated the value of sulfates, particularly with crops containing a high proportion of albuminoids. Lierke (139) reports that fruits responded to fertilizers containing considerable amounts of sulfates. Vermorel and Danthony (239) found that pyrites at the rate of 89.2 to 178.5 pounds per acre augmented the yield of wheat and beans 30 to 60 per cent. Swanson and Miller (224) report no increased yield with the use of potassium sulfate. Call of the Kansas Station did not obtain increased yield of alfalfa or other crops with potassium sulfate.

Application: Tottingham and Hart (230) obtained the best results by application of 100 pounds sulfur per acre. Reimer and Tartar (194) advocate 200 pounds gypsum (15 per cent sulfur), and 250 pounds superphosphate (12 per cent sulfur), or 40 pounds sulfur, or 40 or 50 pounds of sulfur and 200 pounds of rock phosphate per acre annually. Fellers (83) found 200 pounds of sulfur slightly beneficial to soybeans on an arid sandy loam soil, but larger amounts were detrimental. Daikuhara (58) using pot experiments with three soils indicated that less than .02 per cent sulfur-trioxide was sufficient to meet the requirements of barley plants.

Explanation of Increased Yields: The question why sulfur and sulfur compounds increase crop yields in certain cases is an interesting and much disputed one. Bernhard (12), Chanerin and Desriot (49), Boullanger (24), and Heinze (120) think that sulfur functions as a disinfectant or partial sterilizer. Bernhard (12) and Degrully (60) believe that it has a physical effect upon the soil. Cettolini (46) and Boullanger (22) ascribe a catalytic function. Demolon (64) attributed the action of sulfur to the progressive transformation into sulfuric acid thus supplying sulfur to the plant in an available form and rendering other minerals soluble. Tottingham (229), with water and sand cultures of clover, finds an in-

dication that a deficiency of sulfur supply restricted growth by limiting the synthesis of protein.

In regard to calcium sulfate, Greaves and Carter (99) make the emphatic statement that it is the most powerful soil stimulant we have. Referring to Lipman's and Gericke's work, (142) they say this is due mainly to its liberation of plant food, especially potassium. They refer to Briggs and Breazeale (28) to show that there are soils where it does not increase the solubility of potassium, but still gives increased yields. Lipman (147) and Lipman and Sharp (145) point out that gypsum and other sulfates are a specific for black alkali changing the sodium carbonate to sodium sulfate. Lipman and Gericke (142) conclude that all soils do not act alike. Any of the elements may be made soluble from some soils by calcium sulfate and not from others. They obtain conflicting results with different types of soils.

Effect on Root System: The effect of sulfur fertilizers on the root system of plants has been noted by a number of investigators. Reimer and Tartar (194) find that " * * * the root system of alfalfa fertilized with any of the various sulfur fertilizers is from two to three times as large as that of the unfertilized plants." Hart and Tottingham (116) found that the root systems of clover fertilized with gypsum were fully twice as large as on the unfertilized plants. Pitz (189) observes that the root development of red clover is increased by calcium sulfate, small amounts being sufficient. Hart and Tottingham (116) noted that sulfates greatly increased the root development of clover and rape.

Sulfur Fertilization on Nodule Formation: Pitz (189) found that there were three times as many nodules on roots of young red clover plants fertilized with gypsum as on untreated plants. Duley (68) has shown that sulfur and gypsum enormously increase the number of nodules on red clover roots on certain Missouri soils. Reimer (194) found that on some soils the nodules on the roots of alfalfa plants from the fertilized plots have been far more numerous than on those from the unfertilized plots. Miller (171) noted that sulfates

caused increased root development and number of nodules on clover grown in soil plots. Fellers (83) and Wilson (251) found that calcium sulfate depressed nodule formation of soybeans as did also zinc sulfate and ferric sulfate but magnesium sulfate stimulated nodule formation.

Sulfofication: Mares (168) records the fact that when sulfur is added to the soils it is changed to sulfates. Degruilly (60) found that sulfur (109 gm. per square meter) was largely oxidized to sulfates. Brioux and Guerbet (32) noted that in an inoculated soil 94 per cent of the sulfur added was oxidized to sulfates in 16 days. Pfeiffer and Blanck (187) observed that applications of 267 to 524 pounds of sulfur increased the sulfate content of the soil in proportion to the amount of sulfur added. Duley (68) found sulfur to be oxidized to sulfate in both quartz sand and soil. Shedd (207) added 100 pounds to 7000 pounds of sulfur per acre and found 60 to 80 per cent oxidized in four months. Oxidation in sand was slower than in soil, the more fertile the soil the more rapid the oxidation. Happen and Quensell (113) in reporting experiments on the transformation of sulfur, sulfides and sulfates, conclude that hydrogen sulfide produced by bacterial action or decomposition of organic compounds in the soil passes first into the form of ferrous sulfide which is decomposed, the iron being oxidized and the liberated sulfur oxidized to sulfites and then to sulfates.

Brown and Kellogg (38) find that soils have a definite sulfifying power which is mainly a bacterial action. Some chemical oxidation may take place. Soils differ widely in sulfifying power, depending on the treatment. Organic matter and manure increase the amount of sulfur oxidized. The optimum moisture content was 50 per cent of saturation. Aeration was an important factor, as was also the absence of carbohydrates. Bacteria are essential. McCall and Smith (160) found that manure increased the sulfofication in soil and greensand, large amounts causing increased sulfofication. Organic matter had no effect. Brown and Gwinn (34) noted that phosphorus and manure increased sulfofication in loam soil. Sulfofication varied in different types of soil.

Brown and Johnson (35 and 36) found that gypsum, acid phosphate, rock phosphate, monocalcium phosphate, and rock phosphate with gypsum stimulated oxidation of sulfur on black loam soil. The sulfate and phosphate alone had greater effect than the combination of the two. On the other hand, gypsum in large amounts applied to silt loam in the greenhouse produced a depression in sulfonation. In the soil used, the increases in sulfonation were not parallel with increase in yield. Greaves and Carter (99) state that it is well known that gypsum increases very materially the ammonifying, nitrifying and sulfonifying powers of the soil. Ames and Richmond (3) observed that sulfonation was somewhat depressed in an acid soil by addition of calcium carbonate. In an acid soil the oxidation of sulfur proceeded vigorously approximately 50 per cent being changed to sulfate form.

Effect on Nitrogen: Greaves, Carter and Goldthorpe (100) found that in a Utah very productive, sandy loam soil, sodium sulfate, potassium sulfate, magnesium sulfate, and ferric sulfate decreased or only slightly increased the formation of nitric nitrogen while calcium sulfate increased the nitric nitrogen to a marked extent. Singh (211) noted that ammonification and nitrification were depressed by application of gypsum (100, 500 and 1000 pounds) to a silt loam soil.

Solubility of Phosphorus: Lipman (155) presented data to show that sufficient acid might be produced by oxidation of sulfur to produce soluble phosphate. Organic matter was favorable to the process. He has further shown (155) that oxidation of sulfur has increased the soluble phosphorus from rock phosphate in sand and soil. Brown and Gwinn (34) found that addition of sulfur to soil increased the availability of rock phosphate. Ames and Richmond (3) state that with the addition of calcium carbonate to an acid soil the oxidation of sulfur had actually no effect on rock phosphate; and in a basic soil the solvent action of rock phosphate was much less than in an acid soil. Ammonium sulfate affected the solubility of rock phosphate very little. Brown and Warner (40) composted sulfur and floats with horse and cow manure and

an enormous increase of available phosphorus was obtained up to fifteen weeks time. McLean (164) finds that 100 parts soil, 120 parts of sulfur and 400 of floats is most economical for production of available phosphorus. Fineness increased the efficiency. Aeration is very important. Two per cent sodium nitrate inhibited sulfonation almost entirely. In farm composting, 0.4 pounds of aluminum sulfate and ferrous sulfate each should be added per ton of compost for maximum production of available phosphorus. Absence of large amounts of organic matter is beneficial. Brown and Gwinn (34) in recent experiments with black loam and gray loam soils in pots found that sulfur greatly increased the availability of rock phosphate, manure increased it to a less extent and sulfur and manure gave the greatest increase. The physical and chemical composition of the soil greatly influenced the production of available phosphorus and sulfur. With manure and floats the available phosphorus decreased. Lipman, Blair, Martin and Beckwith (150) concluded that inoculated sulfur seemed to be more effective than uninoculated sulfur for rendering inert mineral plant food accessible to growing crops. Mixtures of inoculated sulfur and ground phosphate rock gave better results than rock phosphate alone.

Greaves (98) found that calcium sulfate increased the organic phosphorus 3.3 per cent but decreased the water-soluble phosphorus 16.5 per cent. "It is therefore quite evident that the increased yield resulting from the use of this compound was due mainly to its action upon the available nitrogen of the soil, for it increased the nitric nitrogen content of the soil 95 per cent, and only to a very small degree, if any, to the more available phosphorus" (100). Greaves and Carter (99) in referring to magnesium sulfate, ferrous sulfate, manganese sulfate, calcium sulfate and other chemical fertilizers state that " * * * it is quite evident from these results that the increased available nitrogen and phosphorus is sufficient to account for the noted increase in crop yields resulting from the use of these soil amendments." Ames and Richmond (4) found that the treatment of manure with acid phosphate, sulfur and calcium sulfate decreased the water-soluble phos-

phorus but the citrate soluble and 0.2 per cent hydrochloride acid-soluble were increased. Greaves and Carter (99) and Laws and Gilbert (137) show an increased amount of phosphorus, 1.55 pounds more being taken from a sodium sulfate treated plot as a twenty year average. Greaves and Carter (99) and Jamison (129) used ammonium sulfate and increased the solubility of phosphates and increased the yield thereby. Krockner and Grahl (136) used ammonium sulfate to increase the solubility of insoluble phosphates.

Brown and Warner (40) composted rock phosphates with manure and sulfur with remarkable increase of available phosphorus as measured by extraction with ammonium citrate. Tottingham and Hart (230) composted a Miami silt loam and a garden soil with rock phosphate and sulfur and found that the water-soluble phosphorus was slightly increased in garden soil. Water-soluble phosphorus decreased with manure and with phosphate compost.

Availability of Potassium: The effect of sulfur and sulfur compounds on the availability of potassium has received much attention. Tressler (232) listed the following authors who were of the opinion that gypsum replaced potassium: Snyder, Hilgard, Aikman, Hopkins, Keith and King, Ingle, Voorhees, and Van Slyke. The following did not find that calcium sulfate had the power to set potassium free: Harter, Curry and Smith, and Murry. Beyer (42) did not find calcium sulfate to have any marked effect on the solubility of potassium. Tressler found that calcium sulfate increased the solubility of potassium in a Demkirk silt loam. In two other soils the calcium sulfate had no effects. Tressler, referring to Way's work (245), states that when the analysis of water from lysimeter tanks containing clay does not show an increased amount of potassium in solution due to the addition of gypsum to the soil, it does not necessarily prove that there is no liberation of potassium by the gypsum because soil absorbs potassium. Tressler further states that when large amounts of gypsum are applied to soils the deleterious physical effect of the addition seems to overcome the benefit derived from its use.

Bradley (26) found that gypsum added both to soils from western Oregon and to mineral pegmatite markedly increased the content of water-soluble potassium. Dumont (69) found that when granitic soils were mixed with one-third their weight of gypsum, moistened and allowed to stand, they gave increased amounts of water-soluble potassium. Morse and Curry (173) noted that gypsum increased the water-soluble potassium of feldspar. Andre (6) observed a greatly increased solubility of the potash of microcline when this was treated with gypsum. Singh (211) found that the use of 1000 pounds of gypsum caused a slight increase of soluble potassium in fallow soil. One hundred to five hundred pounds of gypsum showed no effect. When legume crops were grown, the production of soluble potassium was greatly increased by the use of gypsum, the greater increase occurring with the larger application.

Fraps (85) says: "Additions to sulfate of lime have no such effect upon rendering potash available as has been claimed." Briggs and Breazeale (28) found that gypsum solutions depressed the solubility of the potassium of orthoclase. In a cultivated soil they found that the addition of gypsum actually decreased the solubility of potash. McMiller (165) using various Minnesota clay and silt loams found that when these were mixed with one per cent gypsum, raised to a point of approximating the moisture equivalent, and kept in this condition for three months, they showed marked increase in the content of water-soluble potassium. McCall and Smith (160) noted that in composts of greensand, sulfur, manure, and soil, an appreciable amount of potassium was made soluble through sulfification. The amount of potassium made soluble varied from 9.1 to 41.3 per cent of the total initial amount present. Ames and Boltz (1) found that oxidation of sulfur in soil mixture increased the water-soluble potassium. McCool and Miller (162) found that a saturated solution of calcium sulfate increased the solubility of the soil, (six types were used) as determined by the freezing point method.

Bacterial Activity: The activity of bacteria in the soil seems to play an important role in soil fertility. Its relation to sulfur fertilization has been studied by a number of investigators. The results showed a favorable influence on the development of bacteria in the soil. Boullanger and Dugardin (24) stated that small amounts of sulfur materially increase the activity of ammonifying bacteria. Bosinelli (21) believes that sulfur exerts a stimulating action on the bacteria which break down the nitrogenous matter of the soil to ammonia. Fred and Hart (87) showed small increases in bacteria and slight increase in ammonification and carbon dioxide evolution by adding sulfates to soil. Pitz (189) reported an increase of legume bacteria from the use of gypsum. Lipman (146) showed calcium carbonate stimulated nitrification more than gypsum. Peck (182) found that calcium sulfate stimulated ammonification and potassium sulfate accelerated nitrification. Paterson (180) noted that gypsum promoted nitrification. Severin (204) concluded that gypsum not only prevents loss of ammonia from manure but it increases the speed of decomposition from 10 to 20 per cent. Paterson and Scott (180) stated that gypsum slightly increases nitrification. Prichard (191) showed that calcium sulfate promotes nitrification. (Dezani (65) observed that gypsum from 0.5 to 2 per cent had no appreciable effect on nitrification. Greaves and Carter (100) showed that calcium sulfate, magnesium sulfate and iron sulfate stimulate ammonification. They stated " * * * it is very significant that calcium sulfate and other compounds which we have found to be such marked plant stimulants are also the most active bacterial stimulants. The results point to the conclusion that the stimulation of the plant is due in no small degree to the increased nitrogen and phosphorus due to the increased bacterial activity of the soil."

Vermorel and Danthony (238) found that iron pyrites increased yields of wheat and beans 30 to 60 per cent when used with organic matter but had no effect without organic matter. This would point to increased bacterial activity. Tottingham and Hart (230) observed that composts of rock

phosphate, manure and phosphate, and manure with sulfur increased the bacterial count. Manure alone decreased the bacterial count.

Acidity: Tottingham and Hart (230) noted that Miami silt loam and a garden soil composted with rock phosphate and sulfur showed progressive increase of total acidity up to thirty-two weeks. This acidity was thought to be due to acid salts. Reimer (194) found that acidity developed with large (600 pounds) application of sulfur. Feilitzen (82) observed that sulfur had greatly increased the acidity of the soil. Pfeiffer and Blanck (187) stated that 267 of 524 pounds sulfur per acre made the soil strongly acid. Lint (140) found that 100 pounds sulfur per acre with 20 per cent moisture content increased acidity up to the eighth week. A sandy loam showed much more rapid oxidation than a heavy clay loam. Lower moisture content showed slower oxidation. Pitz (189) noted that sulfur increased soil acidity in proportion to the per cent of sulfur added. Duley (68) found that lime requirement of soil treated with sulfur was directly correlated with the amount of soluble sulfate formed. Ames and Boltz (4) observed that sulfur increased the acidity of water extracts of manure. Shedd (207) found that acidity from sulfur must be neutralized by calcium carbonate.

Gardner, Nolls and Baker (89) found that ammonium sulfate eventually caused acidity and produced crop failure. Gypsum did not prevent the soil from becoming sour. Ames and Boltz (2) noted a case in which sulfur increased the acidity of unsterilized soil when calcium carbonate was included in the treatment with rock phosphate and sulfur. Singh (211) noted that gypsum (100, 500, and 1000 pounds) increased the acidity of Iowa silt loam soil, the larger amount giving the larger increase.

Manure: Ames and Richmond (4) treated manure with sulfur, gypsum, and acid phosphate and found that these reduced the loss of dry matter and nitrogen. Schneidewind (202), Severin (203), Dietzell (67), and Bohme (19) show that when manure is treated with gypsum (5 to 10 per cent) a very small loss of nitrogen occurs. Hall (105) and Schneid-

ewind have each called attention to the harmful effects that may be caused by addition of gypsum treated manure to the soil. Ames and Richmond (4) have found that gypsum treatment of manure produced a gain in yield. Manure treated with acid phosphate, sulfur and calcium sulfate lost only one third as much nitrogen as the untreated manure. The sulfur treated manure increased the acidity.

EXPERIMENTAL

The study of sulfur as a plant food naturally separates into the following divisions: the sulfur content of soil, the sulfur content of the crops raised, the amount of sulfur lost in drainage, the amount carried in the rain, the effect of the application of sulfur or sulfur compounds on the crop yields, the optimum amount and best form of application, and the reason for the effect of sulfur fertilizers on the crop yields. In this last division is included the much discussed effect of such fertilizers on the solubility of potassium and phosphorus and other plant food elements. The experimental work dealing with a number of these factors follows.

Determination of Total Sulfur: One preliminary step necessary to the carrying out of the work was the perfection of a method for the determination of sulfur. The method was originally published and discussed in bulletin 145 of this station. Slight modification has since been made, principally to increase the speed of determination, and the method as finally used is as follows: 0.687 gram of the plant material is weighed into a Parr bomb together with one gram of a fusion mixture consisting of five parts of boric acid, four parts of sodium nitrate, and one part of magnesium, all finely ground and well mixed. To this is added 14 grams (12 to 16 grams) of sodium peroxide and the entire charge is thoroughly mixed. The top of the bomb, with fuse wire adjusted, is tightly screwed in position, the bomb is then placed in an electric circuit, 110 volt, immersed in water, and exploded. The fused mass is washed from the bomb into a 400 cubic centimeter beaker with hot water, acidified with hydrochloric acid and evaporated to dryness and then baked until the silica is dehydrated. The silica is filtered off, thoroughly

washed and the sulfur precipitated in the filtrate by adding cold 10 per cent barium chloride carefully to the surface of the solution and allowing the precipitate to settle over night. The barium sulfate is collected on carefully selected papers, washed and ignited, and a few drops of sulfuric acid added before final ignition is made. The weight of barium sulfate divided by 0.05 gives the per cent of sulfur.

In the determination of sulfur in soil, a 2.061 gram sample is used and the weight of barium sulfate is divided by 0.15 to give per cent of sulfur.

SULFUR CONTENT OF EASTERN WASHINGTON, VIRGIN AND CULTIVATED SOILS

The total amount of sulfur in virgin and cultivated soils at Pullman, Deep Creek, and Almira has been determined by the above described method. The percentages of sulfur in the respective samples of soil taken at various depths have been recorded in Table I.

**TABLE I.—TOTAL SULFUR IN VIRGIN AND CULTIVATED
SOILS IN EASTERN WASHINGTON**

Location	Description	Depth Feet	Pullman Pct.	Deep Creek Pct.	Almira Pct.
North Slope	1. Virgin	1st		.036	
		2nd		.027	
		3rd		.024	
	2. Cultivated	1st		.025	
		2nd		.020	
		3rd		.017	
South Slope	1. Virgin	1st	.018	.036	
		2nd	.021	.025	
		3rd	.014	.025	
	2. Cultivated	1st	.021	.021	
		2nd	.018	.030	
		3rd	.016	.018	
Hill Top	1. Virgin	1st	.016	.028	.034
		2nd	.014	.024	.029
		3rd	.004	.020	.021
	2. Cultivated	1st	.012	.025	.031
		2nd	.012	.014	.027
		3rd	.011	.023	.023
Bottom Land	1. Virgin	1st	.029	.033	.036
		2nd	.025	.036	.023
		3rd	.036	.017	.013
	2. Cultivated	1st	.049	.038	.028
		2nd	.029	.016	.022
		3rd	.008	.016	.015

Calculating the amount of sulfur in the surface six and two-thirds inches from the percentage in the surface foot it is found that the extremes are 246 to 972 pounds of sulfur per acre of cultivated soils. These extremes are found in the Pullman soil, the lower amount being in a hill top soil while the larger amount is in bottom land soil. The average amount for cultivated soils is 556 pounds of sulfur per acre. The extremes in virgin surface soil are 328 and 712 pounds of sulfur per acre, the lower amount is found in the Pullman hill top soil while the larger quantity is found in the Almira bottom land and Deep Creek north slope soil. It will be noted that the Pullman hill top soil contains the least amount of sulfur. The average amount found in these virgin soils is 588 pounds of sulfur per acre.

The largest amount of sulfur in the surface three feet of soil is in the Pullman bottom land where 3208 pounds per acre is found, while the smallest amount is found in the Pullman hill top soil which contains 1253 pounds.

Samples of virgin Palouse soils identified as being typical of the most recent formation have been analyzed for their sulfur content. The results are recorded in Table II.

TABLE II.—PERCENTAGE OF SULFUR IN VIRGIN SOILS OF RECENT FORMATION

	North Slope Per Cent	South Slope Per Cent	Hill Top Per Cent
Kamiak Butte	.011	.0196	
Pullman ..	.0284	.0192	
Colfax	.0224	.0232	
Cedar Mountain			.0372 .0168*

*Second foot, all others are of first foot.

RAINFALL

The amount of sulfur brought down in the snow and rain has just recently received attention at this station. The results are for the four months, November 1920 to February 1921, inclusive. The rainwater was collected on the College Campus and, under the circumstances, it would be regarded as showing a higher sulfur content than would actually be found in the rains of the outlying districts. In the four winter

months, there was a total of 2.58 pounds precipitated. Assuming that the average concentration of sulfur in the rainfall would be the same in the summer months, as it was found to be during these four months and calculating on the basis of the average rainfall of 22 inches, we would obtain a total of 5.57 pounds of sulfur per acre annually brought to the land in this manner.

GREENHOUSE EXPERIMENTS

Plan: Both Wausau, Wisconsin, and Ottawa, Illinois, quartz were digested with nitric and hydrochloric acids, thoroughly washed and dried preparatory for use in the greenhouse experiments. In the earlier investigational work, reagents supposed to be pure chemically were used but some of them had to be discarded in subsequent studies because they contained sulfates in appreciable quantities. In a number of instances pure chemicals were prepared in the laboratory in order to avoid the inclusion of sulfur where it was not desired. The various chemicals finally used for the preparation of the culture solutions were free from impurities.

Several culture solutions, with necessary modifications, were tried among which Loew's and New Jersey (Bulletin No. 282) gave the best results. The formula was as follows:

Ammonium hydrogen phosphate	$(\text{NH})_2 \text{HPO}_4$	3.41 grams
Potassium nitrate	KNO_3	2.32 grams
Calcium carbonate	CaCO_3	11.00 grams
Magnesium carbonate	MgCO_3	.35 grams
Ferric hydroxide	$\text{Fe}(\text{OH})_3$	.19 grams
Sodium chloride	NaCl	.30 grams

The stone jars were vitrified ware and measured 20.5 centimeters in diameter and 23 centimeters in depth. Small flower pots were inverted and placed in the bottom of jars. Glass tubes were inserted in the apertures of the flower pots to serve as means of conducting distilled water to the bottom of the jars.

Twenty-five and one-half pounds of prepared quartz were added to each jar in the first half of the series of jars and eighteen and one-quarter pounds of Palouse soil were added to each jar in the other half of the series. During the grow-

ing period a 10 to 12 per cent moisture was maintained in the quartz series and 20 per cent moisture was regarded about right for the soil series.

The quartz series was divided into two lots, one of which (numbers 1 to 10) received the plant food without sulfur, while the other lot (numbers 11 to 20) received 0.60 gram of calcium sulfate. In an earlier series as much as 1.8 gram of sulfur was used in the sulfur containing culture medium.

In the 1915 and 1916 experiments, the soil series were treated with 2 grams of potassium nitrate and 3 grams of ammonium acid phosphate. In one-half of the series (numbers 31 to 40), 3 grams of elemental sulfur were added. All the soils were devoid of nodule forming bacteria.

Spring varieties of wheat (Bluestem No. 392), oats (Swedish Select), barley (Eureka), peas (Bangalia), and Vetch (Hairy) were planted in duplicates in both the quartz and soil series. An additional jar (number 41) of soil contained gypsum in place of the elemental sulfur and the vetch grown under this condition made a wonderful growth. All of the vetch plants were eventually destroyed by the red spider. Soybeans (MacDonald College No. 92) were substituted for the vetch in the years 1915 and 1916. Alfalfa (Turkestan) replaced the soybeans in the year 1917. During the growing period considerable trouble was experienced in the control of aphids as no burning of sulfur or tobacco was permitted. The aphids, however, were kept in check by gently brushing the different parts of the plants. Mildew also appeared on the wheat and a sulfur-free solution of ammonium cupric carbonate was used for its control.

For the 1914 and 1915 experiments, Ottawa, Illinois, quartz was used which undoubtedly contained some toxic substance which was not met with when using the Wausau, Wisconsin, quartz in previous and subsequent experiments.

Yields: The results from the quartz series of experiments were rather irregular and unsatisfactory, especially in 1914 and 1915, due to causes previously noted. However, in 1916

and 1917 the quartz containing gypsum in the plant culture showed striking increases in yield of total dry matter, when compared with yields obtained in the absence of gypsum. (See Figures 1 to 5).

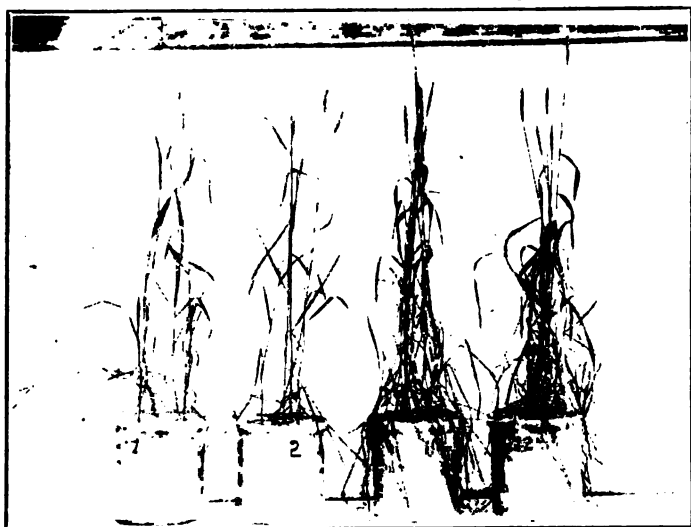


Fig. 1. Wheat. A very small quantity of sulfur remained even after thorough digestion of the quartz. This quantity and that contained in the wheat were the source of sulfur of plants grown in Pots Numbers 1 and 2. Pots 11 and 12 each received an application of 0.60 grams of gypsum.

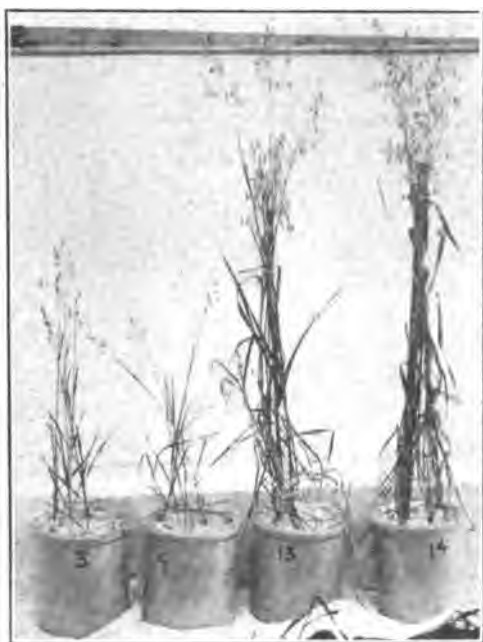


Fig. 2. Oats. Application of 0.6 grams of gypsum to each of Pots Numbers 13 and 14. No application of sulfur to Pots Numbers 3 and 4.

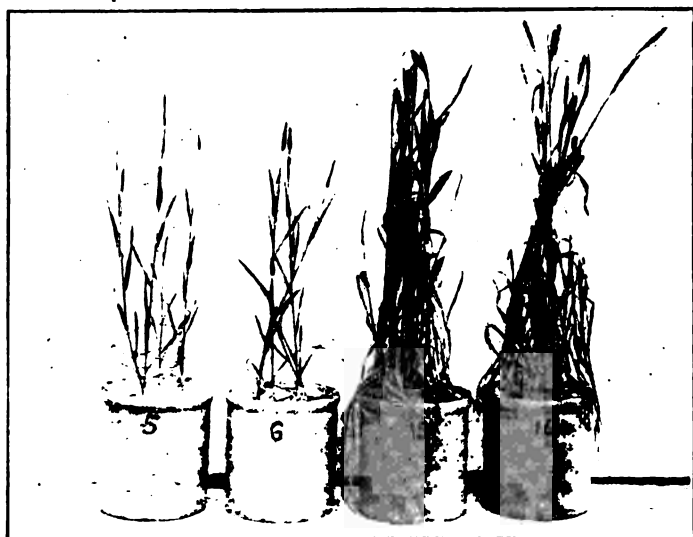


Fig. 3. Barley. Application of 0.6 grams of gypsum to each of Pots Numbers 15 and 16. No application of sulfur to Pots 5 and 6.

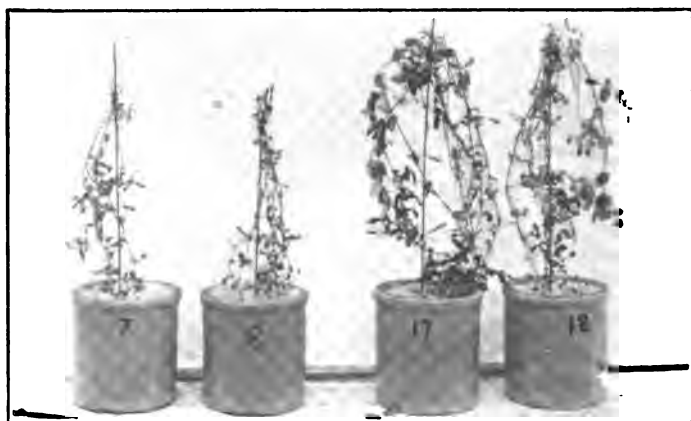


Fig. 4. Field Peas. Application of 0.6 grams of gypsum to each of Pots Numbers 17 and 18. No application of sulfur to Pots Numbers 7 and 8.

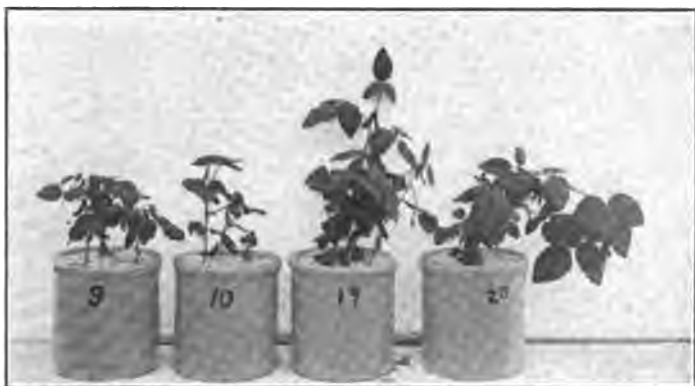


Fig. 5. Soy Beans. Application of 0.6 grams of gypsum to each of Pots Numbers 19 and 20. No application of sulfur to Pots Numbers 9 and 10.

The yields of total dry matter from soils with and without sulfur applications were much larger in 1914 and 1916 than in the other two years. The yields for 1916 and 1917 on both sulfured and unsulfured soils were larger than the correspondingly treated quartz series with the exception of soybeans and one pot each of oats, barley and peas. The yield from the unsulfured soil was much larger than from the unsulfured quartz. Wheat grown on sulfur treated soil gave a larger yield in all cases than that from unsulfured soil. Oats gave increased yields with sulfur treatment in all but the first year trial. Sulfur treatment increased the yield of barley each year while with peas it increased the yield in three out of four years. Soybeans yielded about the same with and without treatment but alfalfa yielded more on the untreated soil.

TABLE III.—TOTAL GRAIN AND TOTAL DRY MATTER REMOVED FROM QUARTZ AND SOIL

		Wheat Grams x	Oats Grams x	Barley Grams x	Peas Grams x	Soybeans Grams x
1. Dry Matter, Quartz						
Untreated:	1916	9.48	4.68	5.00	4.43	7.06
	1917	5.38	9.10	8.45	10.05	4.13*
Treated:	1916	26.61	31.9	26.10	22.47	18.55
	1917	9.68	23.70	18.03	26.63	24.28*
2. Dry Matter, Soil						
Untreated:	1914	55.01	70.64	58.18	34.68	
	1915	17.90	15.80	17.83	9.7	20.59
	1916	39.7	39.63	35.18	31.5†	11.28
	1917	11.58	14.95	17.40	44.25†	41.23*
Treated:	1914	59.12	65.54	61.37	44.26	
	1915	22.60	20.03	22.73	11.70	20.28
	1916	45.69	43.82	38.38	34.05	11.16
	1917	13.45	22.28	17.58	21.35	35.88*
3. Grain, Quartz						
Untreated:	1916	2.58	1.60		1.50	2.00
	1917	1.50†	1.23		6.98	
Treated:	1916	5.10	12.25	5.64	12.52	3.08
	1917	1.43	4.65†	5.40†	13.78	
4. Grain, Soil						
Untreated:	1914	18.61	9.19	17.13	18.23	
	1915	6.95	3.08	2.03	3.90	3.25
	1916	14.90	13.08	7.04	16.7†	1.43
	1917	2.03	3.9		24.6†	
Treated:	1914	21.27	8.90	17.72	18.76	
	1915	8.90	7.65	4.99	5.05	2.91
	1916	15.29	16.26	12.10	16.1	1.75†
	1917	2.80	7.25		10.68	

x Averages of two pots.

* Alfalfa.

† One pot.

Comparing the yields of grain from the sulfur treated and untreated soil, it is found that an increase was obtained in all cases except for oats in 1914. Barley derived the least benefit from the sulfur treatment.

Sulfur Removed: Comparing the total amount of sulfur removed by the crops, it is found that more was removed from the treated than from the untreated quartz. There was more removed from the soil than from the quartz except in the case of soybeans grown in the presence of sulfur. The total amount of sulfur removed from sulfured soil by wheat, oats, peas and alfalfa was greater than from unsulfured soil. The same was true of barley except in 1915, and soybeans

removed less from sulfured soil in 1915 and 1916. The increased intake of sulfur by alfalfa from sulfured soils was quite large.

TABLE IV.
Total Grams of Sulfur Removed by Crops Grown on Quartz and Soil

		Wheat	Oats	Barley	Peas	Soybeans
Untreated Quartz	1916	.0166	.0056	.0030	.0028	.0086
	1917	.0060	.0038	.0073	.0086	.0063*
Treated Quartz.	1916	.0408	.0518	.0475	.0422	.0485
	1917	.0105	.0332	.0154	.0344	.0480*
Untreated Soil..	1914	.0939	.1453	.1295	.1124	....
	1915	.0577	.0560	.0732	.0293	.0708
	1916	.0709	.0827	.0591	.0565†	.0300
	1917	.0585	.0597	.0706	.0931†	.0998*
Treated Soil...	1914	.1143	.2047	.1303	.1207	....
	1915	.0710	.0815	.0642	.0254	.0470
	1916	.1137	.1909	.1122	.1320	.0298
	1917	.0952	.0825	.0950	.1223	.1791*

*Alfalfa.

†One Pot.

TABLE V.
Percentage Sulfur Found in Various Parts of Plants Grown in Soil Pots

	1914			1915			1916			1917			Average		
	Untreated	Treated	Average	Untreated	Treated	Average	Untreated	Treated	Average	Untreated	Treated	Average	Untreated	Treated	Average
Wheat															
Straw	.15	.17	.16	.21	.16	.19	.16	.20	.18	.20	.09	.15	.18	.16	.17
Grain	.19	.22	.21	.48	.47	.48	.47	.29	.25	.59	.88	.74	.39	.47	.42
Oats															
Straw	.22	.23	.23	.25	.25	.25	.08	.22	.15	.24	.16	.21	.20	.22	.21
Grain	.19	.32	.24	.43	.27	.58	.27	.58	.43	.45	.47	.46	.30	.49	.41
Barley															
Straw	.20	.20	.20	.25	.20	.23	.09	.22	.15				.18	.21	.19
Grain	.25	.24	.25	.45	.29	.37	.20	.37	.29	.40	.64	.53	.33	.39	.36
Peas															
Straw	.20	.20	.20	.18	.15	.18	.13	.14	.14	.17	.08	.11	.17	.14	.16
Grain	.31	.35	.33	.43	.39	.41	.27	.69	.55	.32	.62	.47	.33	.51	.44
Soybeans															
Straw				.36	.37	.37	.15	.26	.22				.25	.32	.29
Beans				.35	.21	.28	.31	.31	.31				.33	.26	.29
Alfalfa															
										.22	.43	.33			

Composition: When the sulfur content of the various crops is considered, it is found that wheat straw was nearly constant in composition for the four years. The wheat grain varied in sulfur content, being less in 1914 and 1916 when larger yields were obtained. The amount of sulfur in straw and grain obtained from sulfur treated soil was slightly higher than the amount found in the straw and grain grown on the unsulfured soil. Oats and barley show about the same relations in composition except that the grain of these two crops shows a smaller variation than the wheat grain.

Calculating from the four year average percentages for the different crops and using Warrington's figures for average crop yields, it is found that wheat, oats, barley, peas and soybeans each remove twelve to thirteen pounds of sulfur, per acre, annually, while a four ton yield of alfalfa removes about 26 pounds of sulfur from the soil.

Phosphorus and Nitrogen Content: Determinations of the phosphorus and nitrogen content of the 1914 greenhouse crops were made. The results of these determinations show that the wheat utilizes approximately 2.65 pounds of phosphorus to every pound of sulfur. Oat plant requires about 3.66 pounds of phosphorus to every pound of sulfur, barley 1.55, and peas 1.09 pounds of phosphorus to every pound of sulfur. On the other hand field grown alfalfa utilizes more sulfur than phosphorus. About one pound of sulfur for every three-quarters pound of phosphorus is required.

Based upon total amount of the elements removed by grain and straw, every pound of sulfur utilized by the wheat plant requires 6.2 pounds of nitrogen, oats 3.5 pounds, barley 4.25 pounds, field peas 5.8 pounds and alfalfa 4.6 pounds. Oats require more sulfur than any of the other crops for every pound of nitrogen utilized. Wheat and peas required proportionately less sulfur in comparison with the nitrogen demand of the other mentioned crops.

FIELD EXPERIMENTS

College Farm Results: In the year 1912 a tract, eight rods wide and twenty rods long, was measured off in a field of

alfalfa on the College Farm and was divided into ten plots, each two rods wide and eight rods long. Each alternate plot was used as a check plot. This tract of land had a good stand of crop on it. The tract had a south and west exposure. The crops of preceding years, and from the check plots, showed a regular increase in productivity across the entire tract from west to east. It would have been preferable to have obtained a field showing a more uniform productivity, but no such tract of sufficient size could be found in any of the alfalfa fields on the College Farm. The regular change in productivity, however, made it possible to ascertain the normal yield of any plot by comparing it with those on each side of it.

Preceding the early spring rains and when the alfalfa was about four inches tall, the entire tract was thoroughly disced lengthwise followed by application of the various fertilizers to the different plots. Immediately after sowing the fertilizers broadcast the treated plots were harrowed. The quantity and kind of fertilizers applied were 95 pounds ground lime stone, 20 pounds gypsum and 20 pounds acid phosphate, with 50 pounds floats and 5 pounds sodium nitrate.

In less than a month's time, a marked difference in the appearance of the alfalfa on two of the treated plots was observed, and this became pronounced as the season progressed. Plots 4 and 6 which had been treated with gypsum and acid phosphate respectively, showed a much darker green color and more luxuriant growth of alfalfa than was observed on any of the other plots. This marked difference in color was noticeable at a distance of more than a mile. The blooming period of the alfalfa grown on the gypsum and superphosphate treated plots was considerably delayed by the more vigorous growth induced by these two fertilizers.

All the alfalfa was cut on June the 24th. Samples of six plants each from nine different points on each plot were taken during the mowing, and immediately carried to the laboratory for analysis. The entire bulk of freshly cut alfalfa was raked up, loaded onto wagons and weighed. The total dry matter grown on each plot was calculated from the per-

centage of dry matter found in the samples taken to the laboratory.

On August the 7th, the second growth of alfalfa was cut, and estimation of the dry matter was made in the manner previously described. It would have been possible to have obtained a third cutting on the gypsum and acid phosphate treated plots but owing to the fact that some of the other plots did not produce growth enough so that they could be cut with a mower, it was desired to let this extra growth be returned to the soil as fertilizer for succeeding crops.

The yield of dry matter and the equivalent yields of hay, per acre, assuming that well-cured hay carries ten per cent of moisture, which is about the average for all samples of good alfalfa hay analyzed at this station, is shown in Table VI.

TABLE VI.
Yields from Unfertilized and Fertilized Plots. 1912

Plot treatment No.	1st cutting pounds	2nd cutting pounds	Total pounds	Calculated as hay-tons per acre
1. Check	2711	1151	3862	2.1
2. Lime Rock	3446	1393	4839	2.6
3. Check	2873	1130	4003	2.2
4. Gypsum	5576	2736	8312	4.6
5. Check	3783	1194	4977	2.7
6. Acid Phosphate	5397	2242	7639	4.2
7. Check	3888	1154	5042	2.8
8. Floats	3364	1152	4516	2.5
9. Check	4142	1343	5885	3.2
10. Nitrate of Soda	5327	1518	6855	3.7

With the exception of floats, all the plots which received treatment gave increases in yield above the average of the two adjoining check plots. The largest yields were obtained on the gypsum and acid phosphate treated land.

It was decided that the total effect of the one application of fertilizer should be determined, before further additions be made. The following year a fortieth acre strip of alfalfa (Plot O) lying to the west of the first check plot was treated with one pound of sulfuric acid diluted with 180 pounds of water. Two other strips of alfalfa were treated with hydrochloric and nitric acid respectively in amounts chemically equivalent to the sulfuric acid supplied.

The application of the sulfuric acid killed the first tender leaves. However, new growth immediately took place which appeared more vigorous and thrifty. The new shoots and leaves showed the same marked difference in color that was observed in case of the plants grown on the gypsum and acid phosphate treated plots the preceding year. The dark green color was discernable at a distance of one-half mile or more. On the other hand, the difference in the color of the alfalfa grown on the gypsum and acid phosphate treated plots was not as pronounced as was observed the preceding year.

The yield of dry matter and the equivalent yield of hay, per acre, computed on the basis of ten per cent moisture for an average good quality of alfalfa hay, is recorded in Table VII.

TABLE VII.
Comparative Yield of Dry Matter and Hay Obtained on Check and Fertilizer Plots. 1913.

Plot treat- ment No.	1st-cutting pounds	2nd cutting pounds	Total pounds	Calculated as hay-tons per acre
0. Sulfuric acid plot	4720	2220	6940	3.8
1. Check	2857	1174	4031	2.2
2. Lime Rock	3227	923	4160	2.3
3. Check	....	....	....	..
4. Gypsum	4516	1857	6373	3.5
5. Check	2752	970	3722	2.0
6. Acid phosphate	5097	1418	6425	3.5
7. Check	2887	1386	4273	2.4
8. Floats	2646	1188	3834	2.1
9. Check	2860	700	3560	2.0
10. Nitrate of soda	3732	1245	4977	2.7

Although the yields are not quite as high as those obtained in the first year of the fertilizer experiments the increases noted are similar. The plot treated with floats gave a decreased yield when compared with yields obtained on the two adjoining check plots. In this connection it was of considerable interest to note that the sulfuric acid treated plot gave a yield which equaled the yields obtained on the gypsum and acid phosphate treated plots. The plots treated with hydrochloric and nitric acids did not show the marked color differences observed in the plots treated with sulfuric acid, gypsum or superphosphate. Neither could any apparent

change in yield be noted from the use of the hydrochloric or nitric acids. The increases noted in the plot treated with nitrate of soda, particularly during the first year, were probably due to the benefits derived from subirrigation. An inspection of the southwest corner of this plot showed the water table to be very close to the surface.

The roots of plants in the various plots were inspected and it was found that the plants in all of the plots were well supplied with nodules. In view of this fact, it has been difficult to reconcile the increases to stimulation of the process of nitrification or to believe that nitrogen might be considered the limiting factor. The results obtained on the nitrate of soda and nitric acid plots also support the above view.

The one element common to the gypsum and acid phosphate fertilizers and sulfuric acid was sulfur. The largest quantity of sulfur applied was in case of the gypsum fertilizer and the plot treated with gypsum also produced the largest yield of alfalfa. The form in which the sulfur exists in the above named materials has been recognized as the most available form for crops.

The next year (1914) all of the alfalfa in the gypsum and acid phosphate treated plots, with the exception of an occasional plant, had receded to its original condition and appearance and showed no further benefits from the treatment when compared with the alfalfa on the adjoining check plots. The alfalfa on the plot treated with sulfuric acid was of the darker green color and thrifty appearance.

The total benefit from the applications of gypsum and acid phosphate lasted two years and further treatment with these two forms of fertilizer was considered but the plans of continuing the experiment had to be abandoned because the plots were in a field where a rotation system of farming was followed. The application of 200 pounds of gypsum had increased the yield of dry matter 88 per cent and 200 pounds of acid phosphate had increased the yield of dry matter 80 per cent. The one year yield of dry matter from the application of sulfuric acid amounted to an increase of 78 per cent.

Farmers' Results: The application of gypsum to farmers' alfalfa fields, in various parts of Eastern Washington was made and the same characteristic marked improvement in color and increased yields as found on the College Farm were obtained. In one field in Western Idaho, where it had been impossible to grow profitable crops during the past twenty-eight years, large yields of clover are now being obtained as a direct result of the use of the gypsum in these fields. The farmers in this section seem to be satisfied that gypsum treatment is also very beneficial to increased production of timothy hay.

While numerous examples could be given where applications of gypsum have produced substantial increases in yields of alfalfa, perhaps the results obtained on Mr. H. H. Curtiss' farm located near Pullman, Washington, will suffice. (See Figures 6, 7, 8, 9, 10.) The yield of dry matter was determined and the amount of hay was arbitrarily recalculated to a ten per cent moisture basis.



Fig. 6. Large bundle of alfalfa and crop on right was from part of field treated with gypsum at rate of 200 pounds per acre. The increase in yield was 290 per cent. Small bundle and crop on left was from part of field not treated.



Fig. 7. The alfalfa harvest in a field which had been treated with gypsum.



Fig. 8. The comparative height of alfalfa growing on both gypsum treated and untreated land. The alfalfa standing knee high was treated with gypsum.



Fig. 9. Taken at the same time and in the same field as Fig. 10. This part of field was treated with 200 pounds of gypsum per acre. At the time of harvest the alfalfa reached the elbow height. Alfalfa grown in some fields has reached shoulder height.

TABLE VIII.

Yield of Dry Matter and Hay Obtained from the H. H. Curtiss Alfalfa Field Treated with Gypsum.

	Check plot No treatment		200 lbs. plaster per acre—one application for two years	
	1918	1919	1918	1919
Total Green Wt. Sq. Rd.	44.0 lbs.	45.5 lbs.	115.0 lbs.	210.0 lbs.
Total Dry Wt. Sq. Rd.	13.9 lbs.	13.9 lbs.	40.25 lbs.	53.99 lbs.
Total Hay Wt. Sq. Rd.	15.29 lbs.	15.33 lbs.	44.28 lbs.	59.39 lbs.
Total Hay, per acre	1.23 T	1.23 T	3.54 T	4.75 T

There are many alfalfa fields in Eastern Washington where yields will not exceed one to two tons of hay per acre. It is quite possible that the yields can be further increased with the use of the gypsum. In all the fields where the increases in yield have been noted, nodules have been found on the alfalfa plants, and we have been led to believe that applica-

tions of gypsum will prove beneficial wherever the nodules are to be found on the roots of the plants. In some instances, elemental sulfur has been applied to the alfalfa field instead of gypsum. Comparing sulfur with gypsum, it is found that sulfur does not show increased yields as quickly as gypsum, probably due to the time required for the oxidation of elemental sulfur to the sulfate form.

Removal of Plant Food: With increased production there is also an increased removal of plant food from the soil. In



Fig. 10. The roots of the alfalfa growing in this field were well supplied with nodules, but sulfur was evidently the limiting factor.

order to learn how much plant food was removed from the soil, analyses of samples collected from the various check and fertilizer plots on the College Farm were made and the pounds of potassium, phosphorus, calcium, sulfur and nitrogen contained in crops grown on the various check and treated plots were computed.

The total yield of dry matter obtained on the check plot for the two year period was 27.8 pounds while the total dry matter obtained on the plot treated with gypsum, during the same period was 94.24 pounds. (See Figure 11.) Computed on the basis of tons of alfalfa hay per acre, there was obtained an increased yield of 5.84 tons from the application of 200 pounds of gypsum per acre. Mr. Curtis has again applied gypsum to his alfalfa field and the increases noted above have continued, thus showing that the increases obtained can be maintained through further application of gypsum.

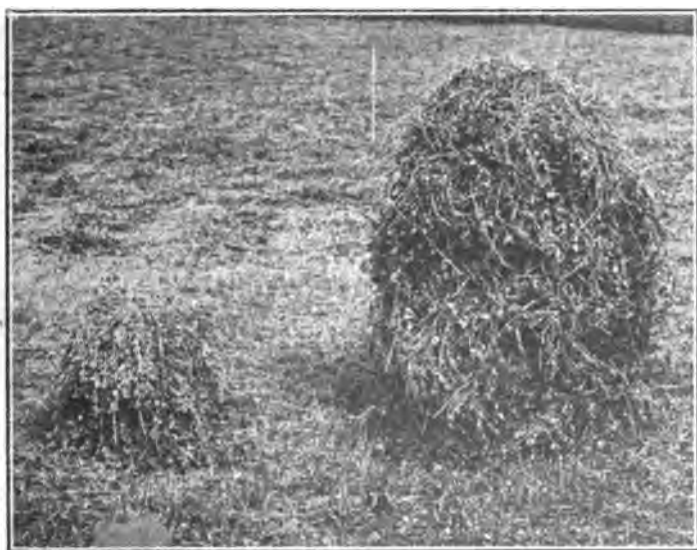


Fig. 11. Comparative yields of alfalfa grown on two plots. The small cock on left is from untreated plot, while the large one to the right is from plot treated with gypsum.

TABLE IX.

Total Plant Food Added to Soil and Removed by Crop in Two Years, Per Plot.

Plot No.	Pounds of plant food added	Pounds of plant food removed				
		Nitrogen	Potassium	Phosphorus	Calcium	Sulfur
0. Sulfur 1.3*		13.2	12.1	2.1	10.9	3.5
1. None		15.0	12.2	2.4	12.5	3.4
2. Calcium, 38.0		17.6	13.9	2.8	14.6	4.0
3. None		7.7	6.4	1.3	6.3	1.3
4. Calcium, 4.8—Sulfur, 3.7		30.1	24.1	5.8	21.0	6.9
5. None*		16.5	14.7	2.6	13.5	3.7
6. Calcium, 4.8—Sulfur, 1-6 Phosphorus, 3-1		28.1	24.1	4.8	20.7	7.0
7. None		17.7	15.3	2.8	13.8	3.9
8. Calcium, 17.9--Phos. 8.7		16.6	14.5	2.5	13.4	3.5
9. None		18.0	16.0	2.5	12.2	..
10. Nitrogen		23.8	21.7	3.4	18.3	5.8

*One year.

The amount of plant food removed by the alfalfa grown on the check plots varied as follows: potassium, 12.2 to 16 pounds; phosphorus, 2.4 to 2.8 pounds; calcium, 12.5 to 13.8 pounds; sulfur, 3.4 to 3.9 pounds. The amount of plant food removed by the alfalfa grown on the gypsum treated plot was 24.1 pounds of potassium, 5.8 pounds of phosphorus, 21 pounds of calcium, and 6.9 pounds of sulfur. About one pound less of phosphorus and about an equal quantity of the other elements were removed by the alfalfa grown on the acid phosphate compared with the gypsum plot. The increased yield of alfalfa obtained on the gypsum treated plot may be regarded as a direct increase due to the addition of sulfur, since the 3.7 pounds of sulfur added to the plot is about the additional amount of sulfur removed when compared with the quantities removed by the crops grown on the check plots. The amount of sulfur removed by the crops grown on the acid phosphate treated plot, however, is 5.4 pounds more than was added to the plot, and when compared with the average amount of sulfur removed by the two adjoin-

ing check plots it is found to exceed the amount removed from them by 1.6 pounds. The addition of gypsum has conserved the limited amount of sulfur in the soil while the application of acid phosphate has lowered the sulfur content of the soil which is about 400 pounds per acre.

With reference to the removal of phosphorus it was found that the alfalfa grown on the gypsum treated plot removed as much of this element as was removed on the acid phosphate treated plot. The addition of phosphorus has aided in conserving the phosphorus in the soil, but our analyses of soil show that the phosphorus content is approximately ten times as great as the sulfur content.

The amount of potassium and calcium removed by the alfalfa was found to be considerably more than the sulfur and phosphorus removed. However, analyses have shown that the Palouse soil carries approximately 20,000 pounds of potassium and 15,000 pounds of calcium per acre of surface soil.

In a system of farming with legumes included in the rotation, it has been evident that applications of gypsum have caused very profitable increases in alfalfa. This increased yield has been due to the supplying of sulfur which has been utilized by the legumes in comparatively large quantities and showing, therefore, that sulfur has been a limiting factor in the production of alfalfa. Cereals require small quantities of sulfur compared with the quantity utilized by legumes, and about one-half as much sulfur as phosphorus.

With increased yields such as have been obtained with the use of gypsum fertilizer, alfalfa growing has become more encouraging and may well be included in the rotation with cereals. On farms where alfalfa has been grown, it has been noted that better yields of wheat have been obtained and the wheat has been found to be of better milling quality. The soil has been rendered better physically and better water absorption and retention have been procured. The annual growing of cereals on land which has been in alfalfa, in place of the two crops in three years or one crop every two years as with the fallow system, has to be considered as an indirect benefit due to the growing of a legume such as alfalfa.

Quality of Alfalfa and Crops Following: The darker green color noted in the alfalfa grown on the gypsum treated plots is also observed in the cured hay when compared with hay obtained from adjoining untreated plots. This difference in color adds to its merchantable value, and generally the highest colored hays are sold for the best prices.

The protein content of alfalfa grown on gypsum and acid phosphate treated land has been found to be higher than that in alfalfa obtained from adjoining untreated plots. The protein found in the alfalfa obtained from the gypsum treated plots was 30 per cent and that from the acid phosphate treated land was 17 per cent higher than that found in the alfalfa grown on the check plots. Similar relations have been found in farmers' lots of alfalfa. Land which has been in alfalfa has been improved both physically and chemically.

Grain grown on newly turned over alfalfa land tends to burn, especially the winter varieties when sown heavily. Excellent results, however, have been obtained with very light seeding for the first two years followed by heavier seeding in succeeding years. Alfalfa growing has also made it possible to grow continuous crops of wheat and lends itself as an excellent crop in a rotation with wheat or other cereals.

The higher protein (gluten) content of wheat grown on alfalfa land compared with that grown on adjacent fields where the summer fallow system of farming has been in vogue, has added to its market value because such wheat is generally sought by the milling trade.

THE INFLUENCE OF SODIUM NITRATE, CALCIUM PHOSPHATE, GYPSUM AND THE CORRESPONDING ACIDS ON THE SOLUBILITY OF PLANT FOOD IN SOIL FROM ALFALFA FIELD

It is thought that perhaps the various forms of fertilizer and especially the gypsum and acid phosphate applied to the alfalfa soil might have increased the yields of alfalfa due to an augmented solubility of the plant food in the soil. Consequently, samples of soil adjacent to the field plots were brought to the laboratory, dried, pulverized to pass a fifty mesh sieve and thoroughly mixed. Aliquot lots of soil of

500 grams each were divided into four series and subjected to action of various chemicals at the following rates per 2,000,000 pounds of soil: Sodium nitrate, 10 pounds; nitric acid, 7.41 pounds; calcium sulfate, 25 pounds; sulfuric acid, 5.76 pounds; potassium sulfate, 100 pounds; calcium acid phosphate, 150 pounds; phosphoric acid, 3.84 pounds (a). The solubilities obtained with double the above quantities of chemicals were also studied (b).

One hundred and fifty cubic centimeters of carbon dioxide-free distilled water were added to each bottle of soil and the four series were allowed to stand for intervals of two, four, six and eight weeks respectively.

When the time limit had been reached for a series the contents of the bottles were emptied into containers and diluted with 1850 cubic centimeters of distilled water and thoroughly shaken and filtered. It required twelve hours to obtain 1500 centimeters of aqueous solution.

The amount of nitric nitrogen contained in soil subjected to action of various salts during a period ranging from 2 to 8 weeks is given in Table X.

TABLE X.
Parts Per Million of Nitric Nitrogen in Soil at Various Periods.

Treatment		2 weeks	4 weeks	6 weeks	8 weeks	Increase or decrease with time	Average amount liberated	Amount liberated over check
NaNO ₃	(a)	7.16	4.44	1.56	4.64	-	4.45	+4.03
	(b)	3.68	19.89	5.80	5.28	+	8.66	+8.04
HNO ₃	(a)	.00	1.40	1.11	.63	-	.78	+ .36
	(b)	.60	8.51	.74	3.45	+	3.52	+2.90
CaSO ₄	(a)	2.68	9.52	1.38	1.82	+	3.85	+3.43
	(b)	.00	12.57	1.40	1.41	+	3.84	+3.42
H ₂ SO ₄	(a)	1.48	3.84	1.07	1.17	+	1.89	+1.47
	(b)	.00	.00	.59	.33	+	.23	- .19
K ₂ SO ₄	(a)	1.48	1.82	1.19	1.42	±	1.48	+1.06
	(b)	.00	.00	.02	.45	+	.12	- .30
CaHPO ₄	(a)	.00	7.90	2.11	2.25	±	3.06	+2.64
	(b)	.00	.00	1.00	3.40	+	1.10	+ .68
H ₃ PO ₄	(a)	1.08	8.20	.05	.96	±	2.57	+2.15
	(b)	.00	.00	.41	1.53	+	.48	+ .06
Check		.00	.00	.16	1.55	+	.42	0

According to the results (Table X) the greatest quantity of nitric nitrogen was soluble at the end of the four weeks period. Some of the samples showed only a slight increase or remained the same. Each chemical showed a small liberation of nitrate with the exception of the double amounts of sulfuric acid and potassium sulfate which resulted in decreases. As would be expected, the greatest amount of nitrate was found in the case of the sodium nitrate treatment.

The quantity of calcium resulting from chemically treating the soil is shown in Table XI.

TABLE XI.

Parts per Million of Calcium in Aqueous Extract of Soil Variously Treated.

Treatment		2 weeks	4 weeks	6 weeks	8 weeks	Increase or decrease with time	Average calcium liberated	Amount liberated over check
NaNO ₃	(a)	53	59	63	63	+	59	4
	(b)	60	58	61	62	++	60	5
HNO ₃	(a)	61	67	43	65	+++	59	4
	(b)	31	51	58	63	+++	51	4
CaSO ₄	(a)	69	43	51	56	—	55	0
	(b)	67	52	55	59	—	58	3
H ₂ SCl ₄	(a)	66	56	62	63	—	62	7
	(b)	69	64	64	65	—	65	10
K ₂ SO ₄	(a)	54	60	61	64	+	60	5
	(b)	52	43	34	38	+	42	13
CaHPO ₄	(a)	58	59	63	64	+	61	6
	(b)	56	58	53	54	+	55	0
H ₃ PO ₄	(a)	54	48	48	51	—	50	5
	(b)	60	55	55	55	—	56	1
Check		61	57	50	54	—	55	0

The data presented in Table XI show that the sodium nitrate and nitric acid treatments increased the water soluble calcium while calcium sulfate, calcium acid phosphate, sulfuric acid, and check showed a decrease with time. In the case of the sodium nitrate and nitric acid the increased solubility was probably due to the formation of calcium nitrate,

which is readily soluble in water. The decrease with sulfuric acid, which is very slight is probably due to the formation of calcium sulfate which is relatively insoluble; calcium acid phosphate and phosphoric acid remained fairly constant.

The amount of phosphorus resulting from chemically treating the soil is shown in Table XII.

TABLE XII.

Parts Per Million of Phosphorus in Aqueous Extract of Soils Variouslly Treated.

Treatment		2 weeks	4 weeks	6 weeks	8 weeks	Increase or decrease with time	Average phosphorus liberated	Amount liberated over check
NaNO ₃	(a)	3.9	3.9	4.7	4.6		4.3	.4
	(b)	3.5	3.5	5.6	4.7	++	4.3	.4
HNO ₃	(a)	4.4	3.8	2.7	3.1	—	3.5	.4
	(b)	2.8	3.9	5.77	5.1	+	4.4	.5
CaSO ₄	(a)	4.3	3.5	4.1	3.7	—	3.9	0
	(b)	3.1	3.9	5.6	5.3	+	4.5	.6
H ₂ SO ₄	(a)	3.8	3.4	5.9	5.5	++	4.4	.5
	(b)	2.5	2.9	5.1	5.0	++	3.9	0
K ₂ SO ₄	(a)	4.0	3.9	4.7	4.2	++	4.2	.3
	(b)	3.6	3.7	4.9	4.5	++	4.2	.3
CaHPO ₄	(a)	3.5	3.8	5.8	5.7	++	4.7	.8
	(b)	4.7	4.5	6.2	6.4	++	5.4	1.3
H ₃ PO ₄	(a)	3.7	4.5	4.0	5.0	++	4.3	.4
	(b)	3.0	3.6	4.5	4.5	+	3.9	0
Check		3.4	3.7	4.4	4.2	+	3.9	0

There seems to be a general increase of soluble phosphorus from all the treatments with the exception of the single application of nitric acid and calcium sulfate. However, the increase was not marked. Calcium acid phosphate liberated the largest amount when compared with the check. There was a small amount liberated by the smaller application of phosphoric acid while the double quantity showed no increase over the untreated solution.

The amount of potassium resulting from chemically treating the soil is shown in Table XIII.

TABLE XIII.
Parts Per Million of Potassium in Aqueous Extract of Soil Vari-
ously Treated.

Treatment		2 weeks	4 weeks	6 weeks	8 weeks	Increase or decrease with time	Average Potassium liberated	Amount liberated over check
NaNC ₃	(a)	20	18	32	30	+	25	1
	(b)	17	26	29	32	+	26	1
HNO ₃	(a)	23	20	16	17	+	19	3
	(b)	21	34	26	27	+	27	3
CaSO ₄	(a)	17	24	35	30	+	26	2
	(b)	18	23	30	31	+	25	1
H ₂ SO ₄	(a)	11	17	26	23	+	19	5
	(b)	27	35	27	29	+	29	5
K ₂ SO ₄	(a)	23	24	17	21	—	21	3
	(b)	26	23	15	24	—	22	2
CaHPO ₄	(a)	21	24	25	27	+	24	0
	(b)	36	26	22	25	—	27	3
H ₃ PO ₄	(a)	26	24	26	24	—	22	2
	(b)	25	18	23	17	—	21	3
Check		33	26	18	22	—	24	0

In Table XIII it will be seen that sodium nitrate, nitric acid, calcium sulfate, sulfuric acid and calcium acid phosphate continued to increase the water soluble potassium. The phosphoric acid, potassium sulfate and the check showed decreases. The increases may be due to the formation of potassium nitrate in the case of sodium nitrate and the nitric acid; or due to a substitution of potassium for calcium in calcium sulfate and calcium acid phosphate.

Collectively, the results obtained compare favorably with those found by Cameron and Whitney and King as will be seen from the data presented in Table XIV.

TABLE XIV.
Plant Food in Parts per Million of Dry-Soil.

	N	Ca	P	K
Whitney and Cameron	1.20	11.67	2.45	22.74
King	8.32	76.68	4.94	16.77
Authors	1.55	55.00	3.9	25.00

With the single exception of potassium, King obtained higher results than were obtained by either Whitney and

Cameron or the writers . The widest variation observed is in the case of calcium which is five times more than that found by Whitney and Cameron.

The chemicals employed have not appreciably increased the solubility of the soil plant food. Sodium nitrate, calcium sulfate, calcium acid phosphate and sulfuric acid very slightly increased the solubility of the plant food in the order named. All other chemicals produced variable results when compared with those obtained on check samples.

In the field experiments the best growth of alfalfa was obtained on the gypsum or calcium sulfate treated plot. In the studies of the solubility of plant food, sodium nitrate has had the most pronounced effect. Evidently, the increased yield is not due to the increased solubility of plant foods produced by calcium sulfate, but is due to the fact that this compound supplied needed sulfur.

SUMMARY

Soils: The amount of sulfur contained in the surface seven inches of the soils studied, varies from 246 to 972 pounds. The amount found in virgin soils varies from 328 to 712 pounds. The average amount of sulfur in these cultivated soils is 556 pounds compared with 588 pounds in virgin soil. There seems to be a more uniform distribution of sulfur in virgin than in cultivated soils. The least amount of sulfur found is in cultivated hill top land while the largest amount is in cultivated bottom land. There is a tendency for the sulfur to concentrate in the surface of the bottom land soils. This is undoubtedly due to washing and capillarity.

Rainfall: The data obtained concerning the sulfur content of rain are not sufficient to be considered conclusive and it is felt that considerably more attention should be devoted to this question.

Greenhouse Experiments: The yield of dry matter obtained in the quartz series of experiments emphasizes the importance of sulfur as plant food. The amount of sulfur contained in seed was inadequate for plant growth and when

gypsum was included in the culture medium, greatly increased yields were obtained. The striking differences shown in this series of experiments are largely due to the care exercised in preparing the culture medium in sulfur-free form.

The soil series of experiments show the importance of sulfur as a plant food in view of the fact that the yields of dry matter obtained on the soil treated with sulfur are on the average much larger than were obtained on the untreated soils. One reason why the unsulfured soil produced good yielding crops may be found in the preparation of the soil. It is obvious that soil which has been ground and sifted has been put into a high state of tilth and the soil surface thereby enormously increased. Undoubtedly, the available plant food is increased. The sulfur that has been made available through the various forces at play in these pot culture studies has not been lost but remains in the soil for the crop needs until it has become entirely exhausted by cropping.

Larger wheat and barley crops were obtained on the sulfur treated soil than were obtained on the unsulfured soil. In three out of four years, oats and peas gave increases in the sulfured soil, while soybeans yielded about the same in the sulfured and unsulfured soils. The largest yield of alfalfa was obtained on the unsulfured soil.

There was an increase of grain produced from the plants grown on the sulfured soil (1914 crop of oats excepted). Barley apparently derived the least benefit from the sulfur treatment.

It was found that the crops grown on the sulfured quartz removed more sulfur than those grown on the untreated quartz. The crops grown on both the unsulfured and sulfured soil removed more sulfur than the crops grown on the sulfured quartz. The largest amount of sulfur removed was, in general, by the plants grown on the sulfured soil.

Alfalfa utilized more sulfur than phosphorus, peas slightly more phosphorus than sulfur. Oats utilized more than three and one-half times as much phosphorus as sulfur, wheat more than two and one-half times as much, and barley more than one and one-half times as much phosphorus as sulfur.

It was observed that a low nitrogen containing crop such as oats requires more sulfur per pound of nitrogen than is required for either barley or wheat. Alfalfa requires more sulfur per pound of nitrogen than peas.

Field Experiments: Alfalfa plots treated with gypsum, acid phosphate, or sulfuric acid have yielded two or more times the quantities obtained on land not treated with these fertilizers. These increases have been obtained in inoculated fields of alfalfa. Applications of hydrochloric and nitric acids in amounts chemically equivalent to the sulfuric acid used have not shown any effects on growth. Elemental sulfur applications also have increased the yields of alfalfa but the plant response to sulfur needs has been necessarily slow because the sulfur must first be oxidized to the available form.

It should be remembered that legumes draw upon the soil plant food the same as other crops. Legume inoculation saves soil nitrogen but inoculation does not necessarily enhance production, because increased yields depend upon other plant food materials as well as upon nitrogen, other things being equal. Among these are sulfur and phosphorus. The phosphorus is found in the soil in comparatively larger quantities than sulfur. Therefore, if increased production is desired, applications of some form of sulfur, preferably gypsum, must be made, because the amount of sulfur in the soil is small. The importance of sulfur applications on inoculated soil for increased legume production is, therefore, evident.

The alfalfa grown on sulfured soils has been found to contain a higher percentage of protein than alfalfa from soils not treated and the cured hay has a very rich green color.

The cereals grown on land which had been in alfalfa have been found to contain a high percentage of protein. This improved protein content and better appearance of both the alfalfa hay and cereal has added to their market value.

The Influence of Gypsum and Other Chemicals on Soil: The application of gypsum to the soil has increased the nitric

nitrogen over the amount found in the untreated soil. It has also increased slightly the solubility of the soil potassium but the solubility of the soil calcium and phosphorus in its presence may be regarded as negligible. The largest amounts of calcium were contained in the aqueous extracts of soil treated with either sulfuric acid, potassium sulfate, sodium nitrate or nitric acid. Very little phosphorus was found in the aqueous extracts of the chemically treated soil. The largest amount of potassium was found in the aqueous extract of the soil treated with sulfuric acid. The influence of the chemicals on the solubility of soil plant food was not large when compared with results obtained by Whitney and Cameron or King on soils which had not been treated with chemicals.

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STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISION OF SOILS

THE SILT LOAM SOILS OF
EASTERN WASHINGTON
and
THEIR MANAGEMENT

by

F. J. SIEVERS and H. F. HOLTZ

BULLETIN No. 166

January, 1922

All bulletins of this station are sent free to citizens of the state on
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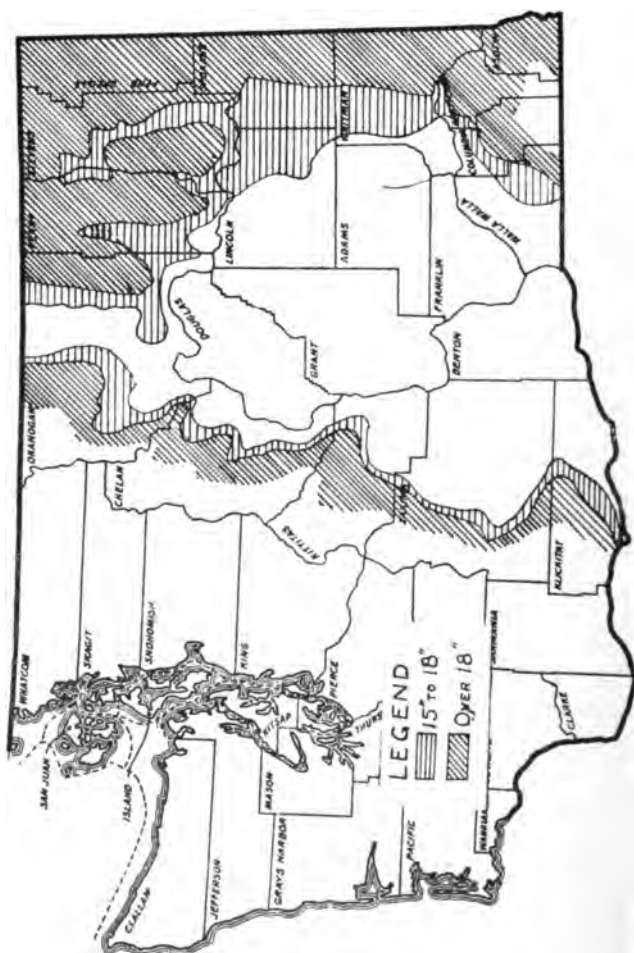


Fig. 1. Map showing the region in Eastern Washington to which this publication applies. Continuous cropping under proper rotation systems is possible where the annual precipitation is above eighteen inches. In the remainder of the area summer-fallowing is necessary.

The Silt Loam Soils of Eastern Washington and Their Management

INTRODUCTION

The importance of climatic and soil conditions in their relation to successful crop production is generally appreciated. These conditions are extremely variable in the state of Washington and have such a pronounced effect on the agriculture that no system of soil management can be recommended for general adoption. The results of investigational work show that even in Eastern Washington where dry farming is generally practiced, the subject of soil management can be treated most satisfactorily by dividing the region into two general areas. One of these has a precipitation so low that moisture is directly the limiting factor in crop production, while the production of the other where the precipitation is more abundant is limited by available soil nitrogen. The boundary between the two areas is approximately defined by the 15-inch rainfall line, which shifts slightly from year to year with fluctuations in the precipitation.

The soil in the more arid of these regions is generally classified as a sandy loam and its management has been discussed in Bul. 164 of the Wash. Agr. Exp. Station. The soil in the area covered by this bulletin is in the main a silt loam and practically all of the investigational work used as a basis was conducted on the Experiment Station Farm at Pullman, Wash. The results properly interpreted will apply to all silt loam soils in Eastern Washington receiving more than 15 inches of rainfall annually.

CLIMATE

Soil moisture plays such an important part in the agriculture of Eastern Washington that precipitation, of all climatic factors, deserves foremost consideration. The annual precipi-

tation of this part of the State varies from about six inches at the junction of the Snake and Columbia Rivers, where the altitude is about 350 feet to twenty-two inches near the Idaho boundary and on the foot hills of the Blue and Cascade Mountains, where the elevation is approximately 3000 feet.

Most of the precipitation occurs in the form of rain during the winter season with practically no rainfall during the months of July and August. Very light showers are common, and due to the fact that the winters are rarely cold enough for much freezing of the ground practically all the moisture is absorbed even on the steeper slopes, thus leaving the soil well supplied at the beginning of each growing season. Although there are decided variations in the total annual precipitation, these have little effect on the agriculture of the region when compared to effects caused by the fluctuations in the total rainfall for the months of April, May and June. The rainfall at this season, because of its economic effect on the crops that are climatically adapted, is watched with keen interest by the farmer. The expression so common that "this is an unusual season" is justified with these annual climatic variations in the spring as a basis. Whatever snow falls thaws readily except on the north slopes where it tends to drift in and becomes less exposed to the sun; here it may remain sufficiently long to retard spring tillage operations.

TABLE 1.—PRECIPITATION AT PULLMAN, WASHINGTON, COVERING THE PERIOD FROM 1896 TO 1921

Year	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Total
1893-1894	2.37	4.67	2.53	1.54	5.71	.46	4.07	1.23	1.81	.89	.33	.10	25.71
1894-1895	1.33	2.84	2.55	.91	3.07	1.25	2.85	.81	2.12	.19	.49	.77	19.18
1895-1896	1.33	1.54	2.54	2.22	2.75	1.61	2.03	1.89	2.32	1.73	.15	.70	21.07
1896-1897	.43	.90	8.31	4.83	2.52	3.05	4.95	1.12	1.35	2.44	.59	.54	31.03
1897-1898	1.86	.74	5.78	3.29	3.30	3.14	1.74	1.02	1.94	2.55	.51	1.03	26.90
1898-1899	1.14	.69	1.67	1.41	4.28	2.50	2.06	2.25	1.94	1.53	.12	2.22	21.81
1899-1900	1.51	2.74	2.88	3.54	3.03	1.94	2.47	3.71	2.70	.48	.92	1.04	26.96
1900-1901	1.65	1.54	3.21	2.61	.81	3.34	1.85	.87	1.47	1.34	.67	.04	19.40
1901-1902	1.39	.60	2.55	2.61	1.85	2.29	1.45	1.02	2.42	.05	2.14	.70	19.07
1902-1903	1.23	.20	6.35	2.87	2.89	2.19	3.28	.74	2.27	1.46	.72	1.16	24.15
1903-1904	5.33	1.66	3.38	2.60	2.21	3.42	3.28	1.34	.71	2.73	1.22	.25	28.04
1904-1905	.20	2.06	1.61	2.37	.90	.53	2.60	1.62	1.62	3.46	.02	.18	17.17
1905-1906	3.34	2.29	1.37	1.46	1.80	2.27	1.37	.42	2.54	.82	.21	2.74	20.63
1906-1907	.48	1.01	7.31	5.76	5.57	1.52	1.67	.43	.90	1.65	1.11	1.96	29.37
1907-1908	1.73	.77	1.50	2.61	1.85	1.85	2.07	1.46	1.51	.97	.10	.68	17.10
1908-1909	.90	2.30	1.30	2.02	3.18	2.95	.93	1.62	1.52	.62	1.06	.05	18.45
1909-1910	.85	2.23	5.92	1.89	4.22	2.40	1.35	2.36	1.60	.25	.08	.77	23.92
1910-1911	.76	2.43	3.30	2.24	2.17	2.88	1.52	.27	2.39	.91	.03	.43	19.33
1911-1912	.92	.93	2.51	2.13	2.02	2.84	1.31	1.80	2.85	1.09	.28	2.14	21.82
1912-1913	1.00	1.91	1.86	1.98	4.85	1.28	3.76	1.50	1.60	2.81	.07	.26	22.88
1913-1914	.94	1.93	2.89	.42	4.10	1.78	.49	1.29	1.21	1.26	.13	.00	16.44
1914-1915	1.20	1.67	2.16	1.32	1.45	1.20	1.83	1.59	2.77	.53	.77	.00	16.49
1915-1916	.63	1.23	4.23	3.01	2.54	4.96	4.39	1.02	1.56	2.34	.45	1.24	28.20
1916-1917	.68	.35	3.24	3.15	3.18	1.00	1.96	4.71	2.25	.57	.00	.00	21.08
1917-1918	.84	.00	1.72	6.79	2.52	2.19	1.68	.46	.75	.56	.85	.68	19.05
1918-1919	.73	1.72	1.65	1.87	2.35	4.44	1.74	1.84	1.03	.30	.04	.14	17.85
1919-1920	.49	.94	2.29	2.71	2.62	.27	2.48	2.96	.95	1.56	.70	.92	18.89
1920-1921	2.00	1.33	2.38	2.95	3.04	1.83	2.96	2.34	1.86	.87	.05	.77	22.38
Average Pre- cipitation	1.33	1.54	3.21	2.61	2.88	2.19	2.27	1.56	1.78	1.28	.49	.77	21.49
Average Snowfall	.10	4.10	8.80	13.70	10.00	5.30	.80						42.80

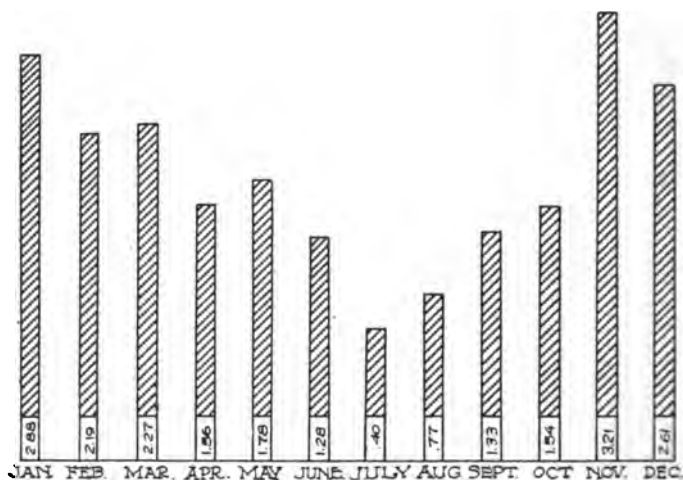


Fig. 2. A graphic representation of data in Table 1, showing the monthly precipitation in inches for the entire year. The low rainfall and low relative humidity and the high evaporation during the summer months makes the region best suited to small grains that mature early.

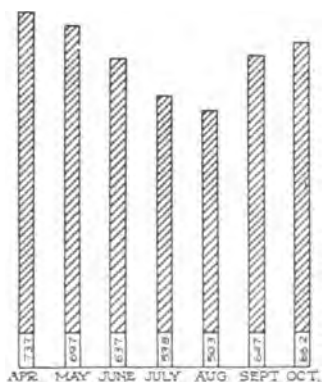


Fig. 3. A graphic representation of data in Table 2, showing the relative humidity during the major portion of the growing season.

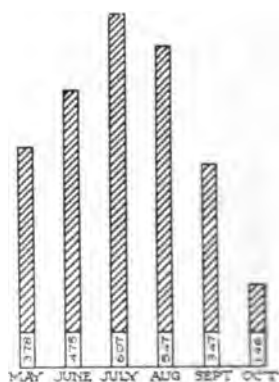


Fig. 4. A graphic representation of data in Table 3, showing the monthly evaporation in inches from a free water surface for the major portion of the growing season.

The climate of this (26*) region is very mild. A twenty-five year temperature record kept at Pullman shows that zero weather is reached for only three days during the average winter while the maximum temperature for the same period of years has not exceeded 90 degrees for more than twelve days per average summer season.

TABLE 2.—THE MONTHLY MAXIMUM AND MINIMUM HUMIDITY DURING THE GROWING SEASON OF 1920 AND 1921

1920	April	May	June	July	Aug.	Sept.	Oct.
Maximum	94.4	90.5	88.3	80.6	81.2	97.0	90.8
Minimum	57.4	48.3	47.9	42.1	41.7	57.4	59.6
Annual Mean	75.9	69.4	68.1	61.3	61.4	77.2	75.2
1921							
Maximum	93.5	81.8	78.8	65.6	54.7	69.6	74.0
Minimum	49.7	48.2	40.4	27.0	24.0	34.9	40.4
Annual Mean	71.6	70.0	59.6	46.3	39.3	52.2	57.2
Avg. Mean	73.7	69.7	63.8	53.8	50.3	64.7	66.2

Over most of this area the relative humidity during the summer is so low that the temperature needs to drop below the freezing point before the air becomes saturated or before the dew point is reached. This low relative humidity makes possible a wide range in daily temperature and subjects the lower valleys to danger of frost during the nights for nearly every month of the year, thus making such areas poorly adapted to crops that are sensitive to this condition. The low humidity also has a pronounced effect on the evaporation which is excessive during the summer on areas that are more exposed to the direct rays of the sun and to the better circulation of the atmosphere. The water requirements under the climatic conditions prevailing during June, July and August (Tables 2 and 3) are very high—so high in fact that only those crops that mature early, or those that are interfilled can be grown successfully.

*Numbers refer to references at end of bulletin.

**TABLE 3.—EVAPORATION RECORDS FOR THREE YEARS FROM
A FREE WATER SURFACE DURING THE GROWING
SEASON***

TIME	LOCATION			
	Hill Top	South Slope	North Slope	Average
1912				
May 11 to 31.....	3.24	3.03	1.98	2.75
May 31 to June 29..	6.33	5.20	3.61	5.05
June 29 to Aug. 2..	5.14	4.46	3.86	4.49
Aug. 2 to Sept. 2...	5.03	4.87	4.01	4.64
Sept. 2 to 30.....	3.74	3.42	2.19	3.12
Sept. 30 to Oct. 5...	.40	.37	.23	.33
Total, 147 days....	23.88	21.35	15.88	20.38
1913				
May 7 to 31.....	3.16	2.63	1.97	2.59
May 31 to June 28..	5.27	4.03	3.23	4.18
June 28 to July 31..	8.18	5.93	5.06	6.39
July 31 to Aug. 30..	6.76	5.05	5.03	4.98
Aug. 30 to Oct. 1...	6.10	5.67	4.63	5.47
Oct. 1 to 22	1.31	1.36	.92	1.20
Total, 168 days....	30.78	24.67	20.84	24.80
1914				
May 2 to 30.....	7.64	6.28	4.07	6.00
May 30 to July 1...	6.65	5.45	2.97	5.02
July 1 to Aug. 1...	9.11	8.39	4.18	7.43
Aug. 1 to 31	8.11	7.73	4.56	6.80
Aug. 31 to Sept. 30.	6.02	4.95	3.32	4.66
Total, 151 days ..	37.53	32.80	19.70	30.01
Three year average.	30.73	26.27	18.18	25.06

*The readings were taken on tanks four feet in diameter and two feet deep. Tanks were sunk in the ground to within four inches of the top and the water in the tanks was kept to within two and three inches of the top. These tanks were placed on the north and south slopes and on the hill tops.

SOIL FORMATION

The major portion of the area under consideration is a plateau having a gentle slope toward the Snake and Columbia Rivers. The geology of the region indicates that this plateau is the result of a basaltic lava flow ejected through crevices in the underlying granitic rock. This lava distributed itself over the entire area at varying depths depending upon the irregularity of the original surface. These depths were sufficient, however, to leave only a few prominences like Kamiak and Steptoe Buttes exposed as islands in this molten sea.

The basaltic rock after being exposed to the influence of the weather for long geographical periods gradually disintegrated and a layer of residual soil was formed on its surface.

This soil layer was modified further by the erosive action caused by the then heavy precipitation with the result that the original plateau is now decidedly cut up by water courses which form an excellent natural drainage system for this entire region. The winds, too, have been very active in modifying the general topography. The particles resulting from the weathering of basaltic rock are of the proper size to be readily transported by the wind and this accounts for the fact that the soil material has been blown away from those sides of the valleys most exposed to the prevailing south westerly winds and has again become deposited on the leeward slopes. The combined action of wind and water has produced a mass of hills and valleys which give the region a strikingly uniformly undulating topography. Where the effect of wind action is most pronounced the hills take on the appearance of dunes having a long gradual slope (20 to 25% grade) toward the southwest and a short abrupt slope (45 to 50% grade) toward the northeast. This has resulted in the deposition of a very deep soil on the latter slopes at the expense of the soil on the windward sides of the hills, to the extent that basaltic rock is frequently exposed.



Fig. 5. A view of representative Palouse topography.

These winds besides influencing the topography are also responsible for the frequent dust storms that carry in con-

siderable soil material from the more arid region to the immediate westward. This continual deposition of soil together with the fact that the entire region was originally a prairie covered with a dense growth of bunch grass (*Agropyron spicata* and other closely allied varieties) has resulted in the formation of a very deep surface soil well supplied with organic matter. The soil in general is a silt loam officially classified as Palouse silt loam. At Pullman this soil contains about 13% sand, 70% silt and 17% clay in the surface foot, (26) but this texture gradually becomes coarser toward the regions where the altitude is lower and the precipitation less.

In their virgin state these soils are very productive and consequently the entire area, except where the rock is exposed, is under cultivation. In common with all soils formed under conditions of limited rainfall, they are well supplied with the mineral elements of plant food and there is comparatively little difference between surface and subsoil. (Table 4).

**TABLE 4.—NITROGEN, PHOSPHORUS, POTASSIUM, CALCIUM
AND ORGANIC CARBON CONTENT OF VARIOUS REPRESENTATIVE
SOIL TYPES OF THE UNITED STATES*
AS COMPARED WITH PALOUSE SILT LOAM OF
EASTERN WASHINGTON**

Soil to a depth of 7 in.	Total N%	Total P%	Total K%	Total Ca%	Total Org.C.%	N-C Ratio
Illinois Prairie Silt Loam	.23	.050	1.75	.523	2.80	1-12.2
Illinois Yellow Gray Silt Loam	.115	.045	1.75	.375	1.25	1-10.9
Iowa Marshall Silt Loam	.163	.066	...	...	1.86	1-11.4
Iowa Grundy Silt Loam	.243	.054	...	...	3.03	1-12.4
Kansas Colby Silt Loam	.14	.038	2.09	1.11	1.77	1-12.6
Kansas Summit Silty Clayey Loam	.275	.040	1.60	.54	3.38	1-12.3
Minnesota Carrington Silt Loam	.37	.089	1.42	.846	4.62	1-12.5
Minnesota Fargo Silt Loam	.615	.118	1.32	1.54	7.59	1-12.3
Nebraska Silt, Central part of state	.186	.061	1.99	...	2.26	1-12.0
Nebraska Silt, Western part of state	.132	.054	2.18	...	1.61	1-12.2
New York Volusia Silt Loam	.145	.031	1.403	.165	1.56	1-12.3
North Dakota Barnes Silt Loam	.396	.068	.739	.978	...	.....
North Dakota Fargo Clay	.347	.064	1.41	1.74	...	.....
Washington Palouse Silt Loam (Virgin)	.202	.082	1.80	1.508	2.595	1-12.8
Wisconsin Colby Silt Loam	.198	.072	1.51	.618	2.26	1-11.4
Wisconsin Knox Silt Loam	.120	.045	1.79	.599	1.44	1-12.0

*Analyses furnished by the Experiment Stations of the States listed in table.

When compared with some of the representative agricultural soils in the United States, Palouse silt loam is slightly above the average in its potassium content (26) and is especially well supplied with calcium and phosphorus. The results of experimental work also indicate a high degree of availability. None of these elements are at present limiting crop production, and consequently there is as yet no justification for their application in a commercial form. The total nitrogen content, although comparatively high is, nevertheless the limiting factor in crop production because the availability of this element is decidedly dependent on climatic conditions which are frequently unfavorable. The percentage of nitrogen in the organic matter as indicated in Table 4 under nitrogen-carbon ratio shows a striking similarity for all soils. Contrary to the more or less generally accepted opinion these soils formed under a limited amount of precipitation contain, if anything, a lower percentage of nitrogen in their (11) organic matter than those from more humid sections.

CROPPING SYSTEM

The system of farming generally practiced in this area consists of winter wheat alternated with the summer-fallow or winter wheat followed by spring wheat, oats or barley and then summer-fallow. In seasons when soil moisture is so limited, as to make fall seeding impossible or inadvisable, spring grain is substituted for winter grain. Field peas, sweet clover, alfalfa, red clover, corn and potatoes are grown to some extent but as yet there is no system of continuous cropping or plan of crop rotation worked out and introduced for general practice. The reason for the lack of serious consideration of a continuous cropping system can, no doubt, be found in the fact that most attempts in the direction of the elimination of summer-fallow have resulted in the introduction of a small grain crop as a substitute. The returns here have been discouraging as far as the resulting yields are concerned, and besides, such a system of cropping also encouraged the growth of troublesome annual weeds to the extent that clean cultivation had to be resorted to, to control these pests. This



Fig. 6. The extreme topography of the land under cultivation has a very decided bearing on all agricultural practices.

has led to a mistaken conviction among most farmers that summer-fallow is absolutely necessary in order that two years moisture may be conserved for the production of one successful crop. Various methods of tillage considered suited for this purpose have been definitely established. The results from these different methods as a rule are decidedly variable and the conservation of total moisture, as such, offers no satisfactory explanation for such variations.

EFFECTIVE SUMMER-FALLOW

To eliminate as far as possible the speculative feature in tillage practice and to determine the controllable limiting factors in crop yields, field experiments were conducted on one-tenth acre plots on the Experiment Station farm. These plots located on soil representative of this region received the

variations in tillage as indicated in Table 5 and were seeded to winter wheat in alternate years in accordance with generally accepted farm practice. Determinations were made of the moisture and nitrates in the surface foot of soil at the end of the summer-fallow season just before the fall rains, of the total moisture and nitrate content of the soil the following spring and of the nitrogen content of the grain. The yields as influenced by the variations in tillage were also recorded.



Fig. 7. Continuous cropping with wheat versus alternate early and alternate late summer-fallow.

1. Wheat continuously, 20.5 bu. per acre.
2. Early spring plowed and early spring disked and harrowed, 52.7 bu. per acre.
3. Late spring plowed and harrowed, 30.6 bu. per acre.



Fig. 8. Where summer-fallowing must be practiced early tillage gives best results.

1. Disked early spring, plowed late spring, yield, 42.4 bu. per acre.
2. Plowed early spring, packed and harrowed, yield, 49.0 bu. per acre.
3. Plowed late in spring and harrowed, yield 36.6 bu. per acre.

TABLE 5.—EFFECT OF DIFFERENT METHODS OF SUMMER-FALLOW ON MOISTURE CONSERVATION, NITRATE ACCUMULATION AND YIELD OF WINTER WHEAT

Tillage Methods	Moisture in Surface ft. Fall, 1913				Moisture to 6 ft. Spring, 1914				Nitrate Nitrogen per A. 6 ft. Spring, 1914				Yield, 1914			
	%	%	Lbs.	Bus.	%	%	Lbs.	Bus.	%	%	Lbs.	Bus.	%	%	Lbs.	Bus.
Fall plowed and Early Spring Disked and Harrowed.	19.1	22.2	70.5	49.4	15.1	20.7	89.9	52.7	15.4	21.6	93.7	21.5	17.5	21.5	110.5	46.0
Early Spring Plowed Packed and Harrowed	17.9	22.6	181.8	49.0	17.5	21.5	110.5	46.0	15.2	21.0	85.8	17.0	15.2	22.3	104.2	44.2
Early Spring Plowed and Harrowed	16.7	23.1	62.6	51.7	15.2	22.3	104.2	44.2	16.5	21.8	94.5	11.8	9.6	19.7	28.6	20.5
Volunteer Growth	10.7	22.0	13.8	20.2	9.6	19.7	28.6	20.5	9.2	21.1	55.2	8.9	11.9	20.4	62.4	32.7
No Tillage	13.8	22.2	102.6	38.5	11.9	20.4	62.4	32.7	11.1	20.9	68.8	8.6	12.1	21.8	46.4	30.6
Late Spring Plowed Packed and Harrowed	13.7	22.9	93.0	36.6	12.1	21.8	46.4	30.6	9.3	21.1	64.8	9.2	11.5	20.1	69.3	31.5
Early Spring Disked	15.9	22.7	123.2	42.4	11.5	20.1	69.3	31.5	15.7	21.0	72.3	10.6	13.1	21.5	61.2	23.2
Late Spring Plowed	12.9	21.8	89.1	37.3	13.1	21.5	61.2	23.2	10.6	20.5	55.0	9.5	10.5	20.6	55.0	34.5
Late Spring Plowed	15.6	22.2	172.2	49.7	10.5	20.6	55.0	34.5	10.4	20.4	52.4	9.3				
Fall Plowed, Late Spring Disked and Harrowed																

The above data in general show a direct relationship between moisture in the surface foot in the fall at the time wheat is seeded, the nitrate nitrogen content of the soil in the spring of the crop year and yield except those of 1918. The 1918 yields are uniformly low and in this respect consistent with the yields generally obtained for the entire area. The reason for this is no doubt traceable to the fact that the seed bed in 1917 was so dry that seeding had to be delayed until the grain had no opportunity to tiller in the fall. The rains the succeeding winter were sufficiently heavy to carry the nitrates beyond the depth where they influenced spring tillering and, due to the cold weather of the succeeding spring, nitrate development was at a minimum with the result that the yields were low.

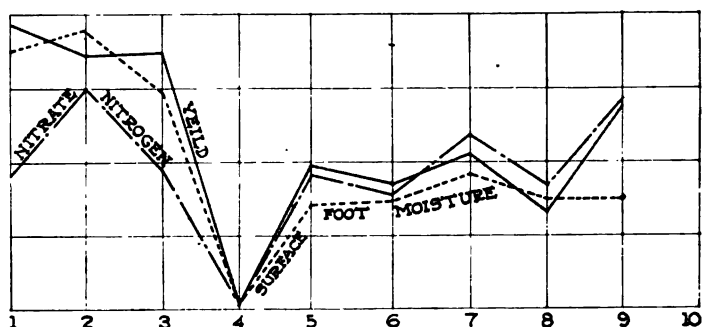


Fig. 9. A graphic representation of data in Table 5 (average for 1914 and 1916) showing the relationship that exists between moisture in the surface foot on summer-fallow, nitrate-nitrogen accumulation and yield of wheat under nine different methods of tillage.

The results show that the total moisture content of all plots in the spring of the year was practically uniform irrespective of the kind of tillage practiced. This moisture content in each case was practically equivalent to the field water holding capacity. The untilled plot had as high a total moisture content as the others thus indicating conclusively, that contrary to popular assumption, summer-fallowing as practiced in this region for the purpose of storing up a two years' water supply (39) to satisfy the requirements of one crop is entirely without foundation.

To bring these soils back to their field water holding capacity requires the absorption of sufficient precipitation to replace the amount removed during the period in which the preceding crop was grown. For three seasons, results with two varieties of wheat (Hybrid 143 and Kubanka) show this amount of moisture to be equivalent to 16.1 inches of rainfall for the production of an average yield of 42.8 bu. per acre (41). This requires the absorption and retention of practically all of the precipitation that comes during one season. Such conservation is possible where the precipitation comes in gentle rains and where the evaporation during the wet season is practically nil. If summer-fallowing is practiced under conditions where the annual rainfall is sufficient to satisfy the

field water holding capacity of the soil, the amount of moisture conserved by summer-fallow tillage must necessarily be lost through leaching.

At the end of the summer-fallow year there were decided variations in the distribution of soil moisture affected by different methods of tillage as evidenced by the moisture content in the surface foot of soil. These variations in surface moisture were paralleled by variations in the soil nitrate content (5) (3) (6) and by the resulting yield the following year. This indicates conclusively that available soil nitrogen and not total soil moisture (4) is the limiting factor in crop production in this region and that the real basis for summer-fallowing is to make the maximum amount of nitrogen ready for plant use. The natural supply of available nitrogen depends upon the decomposition of organic matter which in turn is dependent upon the activities of bacteria in the soil. These organisms for their optimum development require favorable conditions of moisture, air, temperature and organic matter in the surface soil. Of these, moisture and organic matter are the only factors that can be controlled (9) to any extent. It is also very evident from the data (Table 5) that the moisture in the surface foot should be more than 13.5% for adequate nitrate development. This fact is confirmed by results obtained from pot experiments (Table 6) where the moisture content of the soil was very closely controlled.

TABLE 6.—THE EFFECT OF VARYING AMOUNTS OF MOISTURE IN PALOUSE SILT LOAM SOIL ON THE ACCUMULATION OF NITRATE NITROGEN IN 51 DAYS

Moisture Maintained	NITRATE NITROGEN (N)		
	Beginning	End	Accumulation
%	p.p.m.	p.p.m.	p.p.m.
9.65.....	5.0.....	28.8.....	23.8
11.47.....	5.6.....	32.8.....	26.2
13.45.....	5.5.....	40.1.....	34.6
14.35.....	5.9.....	40.9.....	35.0
15.31.....	5.6.....	38.8.....	33.2
16.44.....	5.6.....	39.7.....	34.1
17.44.....	5.6.....	39.0.....	33.4
18.36.....	5.7.....	38.4.....	32.7
19.55.....	5.8.....	39.0.....	33.2
21.53.....	6.0.....	39.5.....	33.5
24.38.....	5.8.....	40.4.....	34.6
27.00.....	6.1.....	39.5.....	33.4

The presence of about 13.5% of soil moisture can be readily determined in the field because it creates a condition under which the small clods or lumps offer very little resistance to the pressure of the hand and the soil allows itself to be readily molded. This amount of moisture present immediately beneath the dry soil mulch in the fall is an indication that the summer-fallow tillage has been effective.

Due to the variations in climatic conditions, especially as they influence the distribution of soil moisture from year to year, the same system of tillage will not necessarily produce the same results for different seasons. This is borne out by the data in Table 5, where the highest yields did not always follow the same tillage practices. Where summer-fallowing is practiced, the tillage that is most effective (33) and which should be followed as nearly as possible, consistent with good farm management, is that which will **keep the highest amount of moisture in the surface soil for the greatest length of time during the summer-fallow year**. For this purpose early spring plowing is essential because the plow furrow at this time of the year is sufficiently moist to settle back into place and re-establish capillary contact with the soil below thus causing the major portion of the furrow slice to remain sufficiently well supplied with moisture to satisfy the demands for nitrification throughout the season. When the plowing is delayed, however, until the plowed soil becomes too dry for capillary movement of moisture the soil is cloddy and will not settle back in place. Such soil turned under will not readily establish capillary contact and consequently the whole stirred layer will dry out. Unless such fallow receives summer rains, which are uncommon (Table 1) the desired nitrification can not take place. For these reasons late spring plowing should not be practiced. The conservation of moisture in the surface soil plays such an important part in the elaboration of plant food and is so dependent on early tillage that a special effort should be made to establish a mulch just as early as possible. This means that where the area to be summer-fallowed is large and all of it can not be plowed early, shallow tillage like disking should precede plowing.

To produce the most satisfactory soil condition throughout the season the plow should be followed immediately by a light surface tilling implement like a harrow. Further tillage is not necessary to maintain a mulch, because the scant rainfall received during the average summer is not sufficient to re-establish capillary contact and therefore does not interfere materially with moisture conservation.

SUBSTITUTES FOR SUMMER-FALLOW

Although the total rainfall is sufficient to grow a crop every year, it is very evident that the proper distribution of moisture plays an important part in promoting nitrification. For this reason results from a continuous cropping system, where moisture distribution through tillage can not be easily controlled, have not always been satisfactory.

Due to the fact that climatic and soil conditions are so excellently adapted for the growth of small grains, little attention has been given to other crops. In cases where continuous cropping has been attempted, the rotation generally included none but the small grain crops and here moisture control through tillage was not possible, (33). Besides the difficulty of controlling the weed situation, which always offers a perplexing problem under this plan, there are other more decided limitations. If land is continually seeded to small grain, a crop requiring a large amount of available nitrogen during (24) the early stages of its growth, unsatisfactory yields result. A corn crop that does not draw heavily on soil nitrogen until later in the season, contrasted to wheat is not affected by a lack of available nitrogen in the spring, but, will produce a satisfactory crop where winter wheat would suffer very materially. The inter-tillage practiced in conjunction with the corn crop will keep the moisture near the surface (27) for a considerable period during the year and thus have the same beneficial effect on nitrification as a good summer-fallow.

TABLE 7.—EFFECT OF SUMMER-FALLOW VS. CONTINUOUS CROPPING ON MOISTURE, NITRATE NITROGEN AND YIELD OF WINTER WHEAT

	Yield, 1913				Yield, 1914				Yield, 1916				Yield, 1918			
	Moisture in surface ft., fall, 1913	Moisture to six ft., spring, 1914	Nitrate Nitro-gen per A. six ft., spring, 1914	%	Moisture in surface ft., fall, 1914	Nitrate Nitro-gen per A. six ft., spring, 1914	%	Lbs. Bus.	Moisture in surface ft., fall, 1915	Moisture to six ft., spring, 1916	Nitrate Nitro-gen per A. six ft., spring, 1916	%	Lbs. Bus.	Moisture in surface ft., fall, 1917	Moisture to six ft., spring, 1918	Nitrate Nitro-gen per A. six ft., spring, 1918
Early summer-fallow	17.9	22.6	104.9	50.3	15.9	21.5	101.5	47.6	15.7	21.5	91.3	16.8	15.7	21.5	91.3	16.8
Late summer-fallow	13.5	22.3	94.9	37.5	12.4	21.2	56.7	31.5	10.4	21.2	62.9	9.1	10.4	21.2	62.9	9.1
Continuous-wheat	10.7	22.0	13.8	20.2	9.6	19.7	28.5	20.5	9.2	21.1	55.1	8.9	9.2	21.1	55.1	8.9
Corn	10.8	22.0	69.5	37.8	11.9	21.8	53.8	45.7	11.3	21.3	79.3	14.2	11.3	21.3	79.3	14.2

The low yield on all plots in 1918 is the result of a very dry and unfavorable fall for seeding in 1917 followed by excessive rainfall, (8.83 inches) in the month of December. The winter grain did not make sufficient growth in the fall to utilize any of the nitrates developed during the fallow year and the leaching resulting from the heavy winter precipitation carried these nitrates into the lower soil before the plants made much development in the spring.

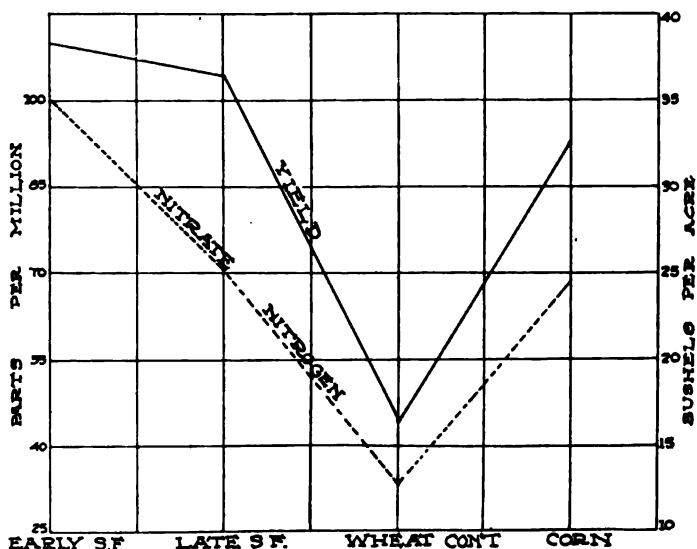


Fig. 10. A graphic representation of data in Table 7, showing the effect of different methods of preparing soil for winter wheat on the total nitrate-nitrogen accumulation and on the yield.

Small grain on the other hand draws the moisture out of the surface soils very early in the season, thus leaving only a very short time during which conditions are such as to make nitrification possible. This results in a lack of sufficient nitrates to produce a profitable crop the following year. Summer-fallow tillage that conserves moisture near the surface, however, also promotes the growth of weeds. These weeds not only draw heavily on the surface soil moisture and thus interfere with the development of nitrates, but also, like any other crop, utilize nitrates already formed and if they are allowed to grow all benefits of the summer-fallow are lost. The tillage subsequent to the spring plowing and harrowing should therefore be of such a nature and frequency as to prevent weed growth most economically.

TABLE 8.—NITRATES IN THE SURFACE FOOT OF SOIL DURING THE GROWING SEASON IN A CORN, WHEAT AND SUMMER-FALLOW FIELD

Treatment	Nitrate Nitrogen		
	June 6	Aug. 13	Oct. 4
	p.p.m.	p.p.m.	p.p.m.
Early summer-fallow	2.9	8.5	8.8
Late summer-fallow	1.0	1.4	2.1
Wheat	1.1	1.1	2.4
Corn	3.9	2.5	12.0

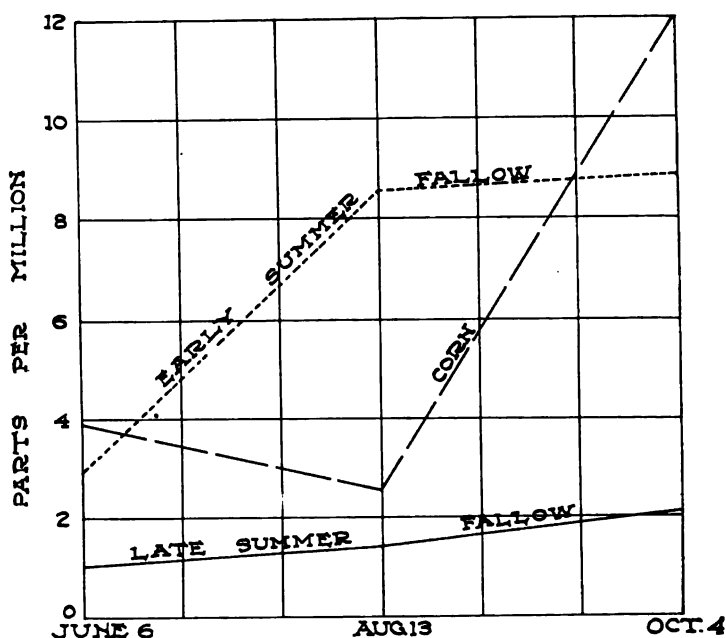


Fig. 11. A graphic representation of data in Table 8, showing the nitrate-nitrogen content in the surface foot of soil in a corn field as compared to the nitrate-nitrogen content in an early and a late summer-fallow field.

RELATION BETWEEN AVAILABLE NITROGEN AND PLANT DEVELOPMENT

Winter grain crops, when planted early in the fall on soil well supplied with moisture near the surface, have a tendency to tiller very profusely. As has been shown before, this soil condition indicates a high nitrate content.

TABLE 9.—THE ADAPTABILITY OF THE YOUNG WHEAT PLANT TO THE NITRATE NITROGEN SUPPLY IN THE SOIL

Nitrate Nitrogen in surface 6 in.	Tillers	Nitrogen Content of Plant
p.p.m.	No.	%
19.6.....	16.1.....	3.92
18.6.....	17.0.....	3.79
8.4.....	12.0.....	3.86
11.0.....	12.5.....	4.07

The data in Table 9 showing the nitrogen content of the plant indicates that the young wheat plant apparently attempts to maintain a uniform nitrogen content (16) in its tissue. To adapt itself to large amounts of available nitrogen in the soil the plant is forced to tiller.

The data in Table 10 obtained under conditions of uniform soil nitrate content, shows that tillering also varies indirectly with the rate of seeding because the lighter seeding leaves more nitrogen available per plant.



Fig. 12. A high nitrate content in the soil results in increased tillering of wheat, a fact worth taking into consideration at seeding time. Four plants per pot. Left, check. Right, .75 gms., sodium nitrate.

TABLE 10.—THE EFFECT OF RATE OF SEEDING WINTER WHEAT (Hybrid 128) ON YIELD AND ON NUMBERS OF TILLERS PER PLANT. UNDER FIELD CONDITIONS
Plots 11x7 feet

Plants per row	Culms per row	Tillers per plant	Rate of seeding per acre	Yield per acre
No.	No.	No.	Lbs.	Bus.
16.1.....	188.....	11.6.....	15.....	57.2
29.9.....	242.....	8.1.....	30.....	61.4
38.5.....	257.....	6.7.....	45.....	60.4
50.0.....	266.....	5.3.....	60.....	62.7
67.8.....	312.....	4.8.....	90.....	63.6
Not calculated	312.....	Not calculated	120.....	60.9
	356.....		180.....	57.9
	384		240	66.8

This variation in tillering, however, is not in mathematical proportion, as there is a tendency for more culms to develop per acre with the heavier seeding at an expense of smaller heads and weaker straw. This extra development of culms is frequently sufficient to cause lodging or "burning," and these conditions, generally consistent with the farmer's expe-

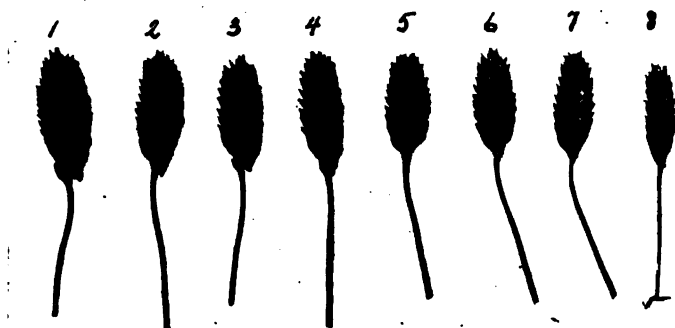


Fig. 13. The size of the wheat spike in the field is directly affected by the number of culms per unit of area, a matter that is influenced by the nitrate content of the soil and the rate and date of seeding. In this case the nitrate content and the date of seeding were uniform, but the rate of seeding varied as follows:

- | | |
|----------------------|-----------------------|
| 1. 15 lbs. per acre. | 5. 90 lbs. per acre. |
| 2. 30 lbs. per acre. | 6. 120 lbs. per acre. |
| 3. 45 lbs. per acre. | 7. 180 lbs. per acre. |
| 4. 60 lbs. per acre. | 8. 240 lbs. per acre. |

rience, result in decreased yields. In the experiment used as a basis for the data in Table 10 all wheat seeded heavier than sixty pounds per acre lodged and the maintenance of yield, in spite of this fact can be attributed only to an abnormally high soil moisture supply. The nitrate nitrogen in these plots during the entire season was more than sufficient to satisfy the demands of the crop and consequently, at no time a limiting factor. There is no intention to specify what the best rate of seeding should be under field conditions because it is recognized that there are too many influencing factors, both soil and climatic, to make such a recommendation possible or advisable for all conditions. One fact is evident, however, and that is that irrespective of the rate of seeding within the limits of this experiment favorable conditions of climate will always assure high yields on fields where the nitrogen supply is not limited, provided (12) (17) the grain is planted sufficiently early to allow time for the necessary tillering.

High nitrate contents are commonly found after a legume has been grown, or in the fall following an early summer-fallow where the moisture has been retained close to the surface and is still in evidence at seeding time. If on such soils heavy seeding is practiced sufficiently early in the fall to provide time for considerable growth and tillering there will be a tendency for lodging or "burning." Lodging occurs in seasons where there is a large moisture supply available, while under conditions where the moisture is inadequate to carry all plants through to maturity, "burning" may result. Either condition generally produces decreased yields. These can be avoided largely by regulating the rate of seeding at planting time or regulating the nitrate supply in the soil, a matter that will be discussed later.

The nitrates developed during the preceding season have no effect on the tillering of spring seeded grain due to the fact that the winter precipitation causes sufficient leaching to carry this soluble plant food down beyond the feeding zone of plants in this stage.

TABLE 11.—THE INFLUENCE OF WINTER RAINS UPON THE MOVEMENT OF NITRATE NITROGEN IN THE SOIL

Depth feet	Nitrate Nitrogen	
	Oct. 6, 1915	April 6, 1916
	p.p.m.	p.p.m.
1.....	15.70.....	1.05.....
2.....	1.31.....	1.90.....
3.....	.95.....	5.50.....
4.....	.81.....	7.50.....
5.....	.81.....	5.00.....
6.....	1.55.....	2.95.....



Fig. 14. Graphic representation of data in Table 11, showing the effect of winter precipitation on the movements of nitrate-nitrogen in the soil.

The nitrates developed in the summer-fallow of the preceding year are found in the sub-soil the following spring at a depth of three feet or more and there are indications that some of them have even been lost in the drainage water. In seasons or under conditions of farm management, when spring planting becomes necessary, the amount of tillering depends upon the nitrates that develop during the spring while the surface is still moist. This nitrate development is largely dependent on the rainfall received immediately after seeding, a factor that cannot be predicted or controlled and consequently the tillering of spring grain cannot be regulated by variations in the rate of seeding. With the limited data available it seems reasonable to assume that spring grain has greater possibilities following a legume than it has when planted on average summer-fallow or when following any other crop. The crop residue left by the legume is high in nitrogen content and much of it decomposes readily. This furnishes the young plant with available nitrates, thus assuring the tillering necessary for a good yield. Due to its lesser tendency to lodge or burn and especially because of the fact that in some

seasons legume sods are difficult to prepare for fall seeding, spring grain may be better adapted to this place in the rotation than winter wheat.

RELATION BETWEEN AVAILABLE NITROGEN AND QUALITY OF GRAIN

Although variations in available soil nitrogen do not affect the nitrogen content of the wheat plant in the early stages they have a decided effect on the nitrogen content and quality (1) of the grain produced. The nitrogen content of market wheat is important because it is proportional to the amount of protein present (39) which in turn directly affects the quality of the flour from a milling standpoint. The milling industry has recognized the fact that the wheat produced in Eastern Washington where nitrogen is the limiting factor is poorer in quality than that grown in the "Big Bend" section, immediately westward where moisture is the limiting factor. It is also becoming more and more evident that the quality is gradually declining as the soil nitrogen becomes more and more limited. There are indications that the future market for wheat will place more emphasis on quality than ever before, thus causing the agriculture of this section to be doubly concerned. Both yield and quality (39) of wheat are directly proportional to the nitrate nitrogen content of the soil, a factor that is largely within the grower's control.

Where all other factors are uniform, good quality of wheat or high protein content is physically indicated by a hard vitreous berry (31) while a mottled or light colored berry indicates high starch content and poorer quality. This latter condition is commonly referred to as "yellow berry" (13) and the relation between it and other factors influenced by nitrate nitrogen in the soil is shown in Table 12. The outstanding fact is that conditions favorable for yield are also favorable for quality irrespective of variety. High yields of wheat under the same condition of climate and soil must therefore necessarily produce grain of lower quality, because the same amount of nitrogen needs to be distributed over a greater weight of product.

**TABLE 12.—RELATION OF NITRATES IN THE SURFACE SOIL
IN THE FALL TO YIELD, TO NITROGEN CONTENT OF
GRAIN AND TO "YELLOW BERRY" OF FOUR
LEADING VARIETIES OF WINTER WHEAT**

Nitrate Nitrogen in surface 6 in.	Yield	Nitrogen in Grain	Yellow Berry	Variety
p.p.m.	bu.	%	%	
34.5	52.9	2.11	5	Turkey Red
23.1	62.3	2.04	10	Turkey Red
23.0	61.2	1.97	17	Hybrid 128
15.6	62.5	1.87	26	Hybrid 143
14.8	48.1	1.76	55	Hybrid 128
14.0	64.7	1.81	45	Little Club
11.2	63.6	1.87	25	Hybrid 143
8.7	56.4	1.63	61	Little Club
8.7	48.7	1.51	75	Hybrid 143
5.0	30.3	1.21	100	Hybrid 128

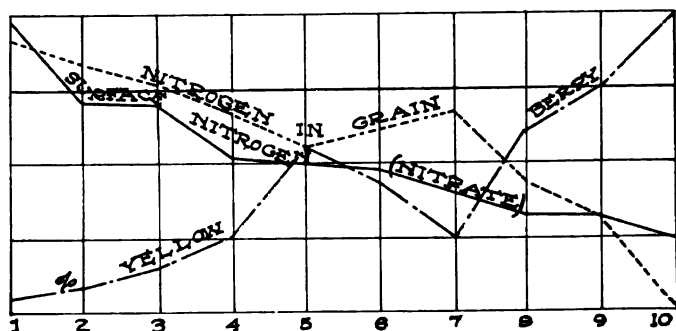


Fig. 15. A graphic representation of data in Table 12, showing the relationship that exists between available nitrogen in the soil, nitrogen in the grain and percentage of yellow berry in the grain in samples taken from ten different localities.

Where spring wheat is seeded after summer-fallow, "yellow berry" is practically unknown, due to the fact that the rain-fall of the preceding winter has carried sufficient nitrates down into the soil to such a depth that spring grain is well supplied with this element after the tillering season is over. When spring wheat is sown, following a small grain crop, however, this fund of available nitrogen does not exist in the lower soil and "yellow berry" is more common.

LOSS OF NITROGEN BY CROPPING AND LEACHING

It has been shown that summer-fallowing is practiced to make nitrogen available under conditions where the precipitation of the succeeding winter is more than sufficient to satisfy the water holding capacity of the soil. There is a loss of nitrogen from the soil as a result and this loss as shown in Table 13 should be practically accounted for in the crops removed and the soil leachings.

TABLE 13.—COMPARISON OF THE NITROGEN CONTENT OF VIRGIN SOIL AND OF SOIL CROPPED FOR 39 YEARS

Sample	Nitrogen in virgin soil	Nitrogen in cropped soil	Loss of Nitrogen through cropping
In.	Lbs. per A.	Lbs. per A.	Lbs. per A.
South Hillside			
0—6	2695.5.....	2378.4.....	317.1
6—12.....	2148.4.....	1489.7.....	658.7
12—24.....	3478.5.....	2272.3.....	1206.0
Total loss in two ft.			2182.0
North Hillside			
0—6	4234.0.....	3962.1.....	1271.9
6—12.....	3098.0.....	2573.5.....	524.5
12—24.....	5330.0.....	4488.4.....	841.6
Total loss in two ft.			2638.0
West Hillside			
0—6	3118.9.....	2099.6.....	1019.3
6—12.....	1968.9.....	1646.6.....	322.3
12—24.....	2721.1.....	2496.6.....	224.5
Total loss in two ft.			1566.1
Average loss to depth of two feet			2128.7 lbs.
Average loss in per cent in 39 years			22.1%

The average loss of 22.1 per cent of nitrogen from the surface two feet of soil (40) over a period of 39 years, represents 2128.7 lbs. The amount of nitrogen necessary for the growth of both straw and grain to produce one bushel of wheat is about 1.7 lbs. This would indicate that enough nitrogen has been lost from the soil to produce 1250 bushels of grain in twenty crops or an average biennial yield of 62¼ bushels per acre under a system of alternate summer-fallow and wheat. Since this theoretical yield is at least 50 per cent greater than that actually obtained it is very evident that there has been a loss of at least eighteen pounds of nitrogen

per acre annually to sources besides those accounted for (45) in the removal in grain and straw.

Although no system of soil management can be so regulated as to confine all plant food losses to crops removed, the amount of nitrogen lost (24) here in proportion to that used is much too high. In a normal season where winter wheat makes sufficient growth to utilize a large percentage of the available nitrogen before the rainy season begins the loss is at a minimum. On the other hand, where soil and climatic conditions in the fall are so adverse as to make very late seeding or even spring seeding necessary, the loss of this available nitrogen through leaching because of heavy winter precipitation, becomes exceedingly large.

The summer-fallow system not only draws steadily on the soil nitrogen necessary for crop production without any attempt at the maintenance of this limited and therefore important element of plant food, but it has, moreover, depleted the soil of at least 50% more nitrogen than is actually removed by the crop. The practice is therefore, not only short-lived but exceedingly wasteful as well.

LOSS AND MAINTENANCE OF ORGANIC MATTER

The evidence is conclusive that the present system of agriculture does not make for permanency, when it is found that after a period of thirty-nine years of farming, during which time only twenty crops were grown, 34.5 per cent of the organic matter (Table 14) and 22.1 per cent of the nitrogen (Table 13) have been lost (2) (8) from the soil.

The loss of organic matter as such has also had a very pronounced detrimental effect on the physical condition of the soil. The erosion on the steeper slopes after heavy rains is becoming so severe that the resulting trenches interfere very materially with field operations and with satisfactory crop development. Fall plowing after a dry summer, following the harvest of winter wheat also has become next to impossible due to the extreme compactness of the soil. Consistent with this condition the winter rains have a tendency to cause a puddling and general running together of the soil, so that winter grain is decidedly handicapped in establishing itself



Fig. 16. The erosion of soils in the Palouse country is a serious problem. It is the result of a system of farming that makes no provision for the maintenance of the organic matter in the soil.

and a proper seed bed for spring grain is difficult to prepare. In the spring of the year, the surface soil very readily forms a crust which becomes exceedingly hard before the soil immediately below is sufficiently dry to plow well. This results either in plowing the land when it is too wet at the lower portion of the furrow slice or otherwise when it is decidedly dry and inclined to become lumpy at the upper portion. This condition is conducive neither to a good seed bed nor to good summer-fallow. To obtain the soil condition essential for optimum nitrification and satisfactory crop development, the farmer finds it necessary to devote more time to tillage operations than formerly in order that the same results in yields may be obtained.

The impression, so prevalent among a certain class of farmers, that the soils are not being depleted but are maintaining their fertility, is not supported by results from analyses. The fact that yields during some seasons on certain fields may be as large as they were under virgin soil conditions can be accounted for only on the basis of greater effort in soil preparation and more favorable seasonal conditions.

TABLE 14.—ORGANIC CARBON IN VIRGIN SOIL AND IN SOIL THAT HAS BEEN CROPPED FOR THIRTY-NINE YEARS

Depth of Sample	Carbon in Virgin Soil	Carbon in Cropped Soil	Loss of Carbon in 39 years
Inches	Lbs. per A.	Lbs. per A.	Lbs. per A.
South Hillside			
0—6	35,457.8	22,277.8	13,190.0
6—12	24,289.0	13,896.5	10,419.5
12—24	37,400.0	17,360.0	20,040.0
West Hillside			
0—6	35,388.1	23,173.9	12,214.2
6—12	22,041.4	17,493.7	4,547.7
12—24	29,856.0	18,835.3	11,020.7
North Hillside			
0—6	52,969.0	33,419.2	19,549.8
6—12	37,897.2	28,993.5	8,903.7
12—24	67,126.0	48,731.5	18,394.5
Average loss to a depth of two feet....			39,426.7
Average loss in per cent			34.5%

Organic Matter Maintenance Through Use of Straw

In the Great Plains section where intermittent showers are common during the growing season the surface soil in a cropped field does not remain dry during the entire summer as it does in Eastern Washington where the summer rains are rare to the extent of being practically unknown. Here, after the soil once dries out in the spring, it generally remains dry until after harvest. This dry soil condition during practically the entire warm portion of the year allows very little opportunity for the decomposition of stubble, straw, or manure, unless an effort is made to retain the soil moisture near the surface through summer-fallowing or growing of an intertilled crop like corn or potatoes. That this organic matter fails to decompose under a continuous cropping system is indicated by its presence in the soil at the bottom of the furrow at the end of the year when the land is again plowed in preparation for the next crop. The presence of this organic matter has a depressing effect on the development of nitrates.

TABLE 15.—DEPRESSING EFFECT OF STRAW ON NITRATE DEVELOPMENT IN PALOUSE SILT LOAM SOIL

Time	NITRATE NITROGEN (N)					
	Hill Top		North Slope		South Slope	
	Check	Straw	Check	Straw	Check	Straw
	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
Beginning	6.0	6.0	5.7	5.7	6.9	6.9
4 days	5.9	7.4	6.8	8.1	7.8	8.7
11 days	5.6	2.2	7.1	2.2	8.1	3.3
21 days	8.2	1.9	9.6	2.1	9.9	2.3
29 days	11.9	1.7	15.2	2.1	14.2	2.3
36 days	12.1	2.9	14.5	4.0	14.5	2.9
111 days	22.4	12.5	27.3	18.9	30.7	12.2

In each case where straw was applied there was an actual loss of nitrate nitrogen (14) (18) (28) (44) (34) in the soil soon after the application was made. It took more than 36 days of ideal conditions for decomposition before the nitrate content again became as high as it was when the experiment was begun.

It was shown in Table 5 that available nitrogen is the limiting factor in crop production and consequently any soil condition that interferes with the development of nitrates will have a detrimental effect on the yield. The data obtained from experiments in the field and plant house, where wheat was grown immediately after straw was applied to the soil, shows the detrimental effect of such application on the yield. In the field this decrease in yield was experienced in all cases where straw was used, either plowed under or applied as surface dressing on spring and winter grain.

This explains in part why the farmer, using his crop yields as an indication, has been inclined in some cases to look favorably upon the burning of stubble in the field. He has been very much opposed in all cases to returning either straw or other crop residue to the soil in spite of the fact that he was theoretically convinced that the return of these materials would prevent the depletion of the organic matter and thus tend to maintain soil productivity. Before the return of straw to the soil can be generally recommended, means must be found to prevent the depressing effect on yield now experienced and it must also be shown that such return actually benefits the soil as regards organic matter maintenance.

TABLE 16.—NITRATE NITROGEN DEVELOPMENT IN SOILS TREATED WITH STRAW, IN AMOUNTS EQUIVALENT TO FIELD STUBBLE AND TO COMPLETE RESIDUE. CONDUCTED IN TWO-GALLON JARS

Time	NITRATE NITROGEN (N)		
	Check	Stubble*	Complete**
	p.p.m.	p.p.m.	p.p.m.
At beginning	1.1	1.1	1.1
After 30 days	10.9	3.2	1.2
After 56 days	22.1	12.2	2.4
After 76 days	17.3	10.7	3.5
After 97 days	22.5	10.6	6.2
After 127 days	24.8	29.1	19.9
After 162 days	28.5	38.4	26.6
After 195 days	39.5	39.5	27.8

The soil moisture in this experiment was maintained at optimum condition for nitrification (15 to 20%) and in this respect was representative of good summer-fallow conditions. Even here it took practically 100 days before the depressing effect of the complete residue on nitrification was overcome. Only after 195 days did the nitrate content of the treated soil approach that of the untreated. It should also be noted that the depressing effect of stubble alone was not as pronounced as where the complete residue was returned.

*11 grams of straw, 15 lbs. soil.

**22 grams of straw, 15 lbs. soil.

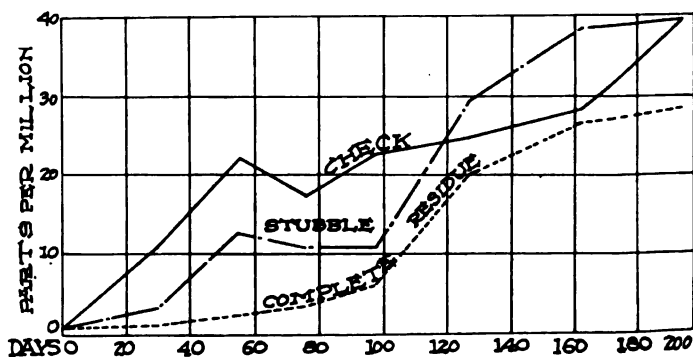


Fig. 17. A graphic representation of data in Table 16, showing the depressing effect of straw applications to the soil on nitrate accumulation. The figure also shows that time is an important factor in overcoming such depressing effect and thus emphasizes the fact that small grain should not be seeded the same season that straw is applied.

**TABLE 17.—EFFECT OF STRAW APPLICATION TO THE SOIL
ON THE YIELD OF THE IMMEDIATELY SUCCEEDING
WHEAT CROP**

Yield in Field		Yield in 2-gal. Pots	
	Bus.		Gm.
Check	28.95	Check	2.16
Straw, 1½ tons per A....	24.50	11 gm. of straw, per pot..	1.01

The data in Table 18 indicate that when the straw was applied alone or when supplemented with vetch in small amounts there was not only a slow development of nitrates (15) but actually a loss of the nitrates originally present. There was no indication that this depressing effect was overcome until 104 days (Table 18) after the application. Where larger amounts of vetch were applied as a supplement, this depressing effect was not so pronounced and when vetch was used alone, nitrate development was actually increased.

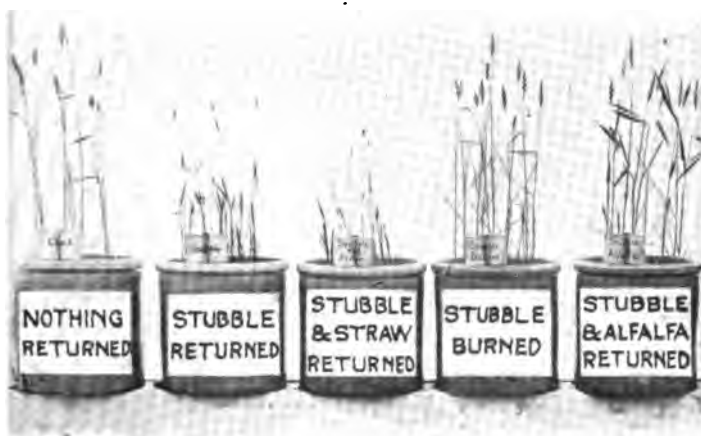


Fig. 18. Straw and stubble returned to the soil have a depressing effect on nitrification and on the resulting development of the wheat plant as well as on the yield produced. This depressing effect can be overcome by limiting the amount of straw returned, by allowing the straw to decompose partly before it is returned or by supplementing the straw with (alfalfa) a high nitrogen carrying material.
1. Check. 2. Stubble returned. 3. Stubbles and straw returned. 4. Stubble burned. 5. Stubble supplemented with alfalfa returned.

TABLE 18.—THE INFLUENCE OF HIGH NITROGEN CARRYING CROP RESIDUES USED AS A SUPPLEMENT TO STRAW ON THE RATE OF NITRATE DEVELOPMENT. PALOUSE SILT LOAM SOIL

Treatment	Nitrogen		NITRATE NITROGEN									
	in residue	0 da.	2da.	4da.	7da.	14da.	36da.	53da.	72da.	104da.		
Check	%	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.		
	0	3.3	3.6	4.6	4.8	7.6	7.3	5.7	7.1	31.6		
Straw 9 Gms.	.50	3.7	3.5	2.2	1.8	1.5	1.3	1.3	1.0	3.6		
Vetch 0 Gms.												
Straw 7½ Gms.	1.07	3.5	4.7	4.4	3.7	1.8	1.4	1.5	.9	4.7		
Vetch 1½ Gms.												
Straw 6 Gms.	1.66	3.3	5.3	7.0	9.9	3.4	1.4	1.8	2.1	19.6		
Vetch 3 Gms.												
Straw 4½ Gms.	2.25	4.0	5.6	7.5	11.5	9.9	5.2	5.9	6.5	20.3		
Vetch 4½ Gms.												
Straw 3 Gms.	2.83	4.0	5.3	8.3	13.2	13.1	16.7	14.3	19.0	40.6		
Vetch 6 Gms.												
Straw 1½ Gms.	3.42	4.0	5.4	8.9	13.2	18.7	29.0	27.5	32.8	45.2		
Vetch 7½ Gms.												
Straw 0 Gms.	4.00	3.7	5.3	8.1	13.2	22.3	40.6	39.5	49.3	75.0		
Vetch 9 Gms.												

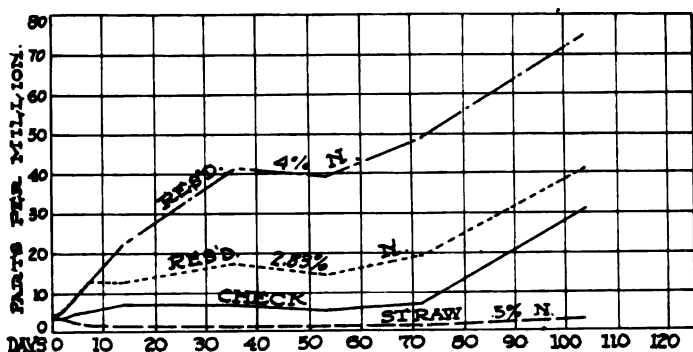


Fig. 19. A graphic representation of data in Table 18, showing nitrate-nitrogen accumulation as affected by the application of crop residues of varying nitrogen content.

This shows that the depressing effect on nitrate development and therefore on the resulting yield can be overcome (20) by supplementing straw with the proper amounts of high nitrogen-carrying crop residues.

The amount of organic decomposition in a soil can be measured by the evolution of carbon dioxide and the changes in the nitrate content. In Table 19, 39.25 per cent of the wheat straw applied is carbon. At the end of 132 days, which covers about the length of time that conditions are favorable for nitrification in the field, the difference in the amount of carbon lost as carbon dioxide (30) from the straw-treated soil over the check is (1.501 gms. minus .493 gms. equals 1.008 gms.) sufficient to account for practically 86 per cent of the straw applied.

On the other hand, 41 per cent of the vetch applied is carbon and at the end of the same period the difference in the amount of carbon dioxide from the vetch-treated soil over the check (1.004 gms. minus .493 gms. equals .511 gms.) accounts for only 41 per cent of the organic matter applied. This, together with the results in nitrate development, would indicate that when a crop residue containing a high percentage of nitrogen is applied, the kind of decomposition (29) that takes place does not go through to completion but apparently results in the accumulation of humified organic matter in the soil. The difference in decomposition of straw as compared to vetch

TABLE 19.—THE INFLUENCE OF HIGH NITROGEN-CARRYING CROP RESIDUE USED AS SUPPLEMENTS TO STRAW ON THE AMOUNT AND KIND OF DECOMPOSITION IN THE SOIL (1000 gms.) DURING 132 DAYS

Treatment				Carbon in residue	Nitrogen in residue	Carbon given off as CO ₂	Nitrate Nitrogen accumulated
				%	%	gms.	p.p.m.
Check	.....	.....	.....	.....	.....	.493	69.3
3 gms. straw	0 gms. vetch	.....	.....	.39.25	.50	1.501	40.2
2 ¼ gms. straw	¾ gms. vetch	.....	.....	.39.75	1.37	1.490	67.5
1 ½ gms. straw	1 ½ gms. vetch	.....	.....	.40.25	2.25	1.137	92.0
¾ gms. straw	2 ¼ gms. vetch	.....	.....	.40.75	3.16	1.017	118.8
0 gms. straw	3 gms. vetch	.....	.....	.41.25	4.00	1.004	141.0

can be explained on the basis of the nitrogen-carbon content of the materials. The former contains nitrogen and carbon in the ratio of about 1:78 while in the latter the ratio is narrowed down to about 1:10. When it is considered that the nitrogen-carbon ratio in soil organic matter varies from about 1:9 to (37) 1:13 (Table 4), it becomes evident that most of the carbon in the straw must be lost before the resulting product will become a part of the soil organic matter.

It is an established fact, borne out by results in Tables 13 and 14, that the gradual destruction of organic matter in the soil as a result of tillage results in a more rapid loss of carbon than of nitrogen and therefore makes for a greater concentration of the nitrogen in the remaining organic matter. In other words the nitrogen-carbon ratio in soils becomes gradually narrower (37) as the organic matter becomes more and more depleted. This has led to the mistaken belief that the organic matter in soils can be most rapidly increased through the use of a crop residue like straw or strawy manure having a wide nitrogen-carbon ratio, because the carbon losses had been heavier than those of nitrogen. Experimental results, however, are consistent with experience under field conditions. The farmer has been unable to influence the physical condition of his soil to any considerable extent through the

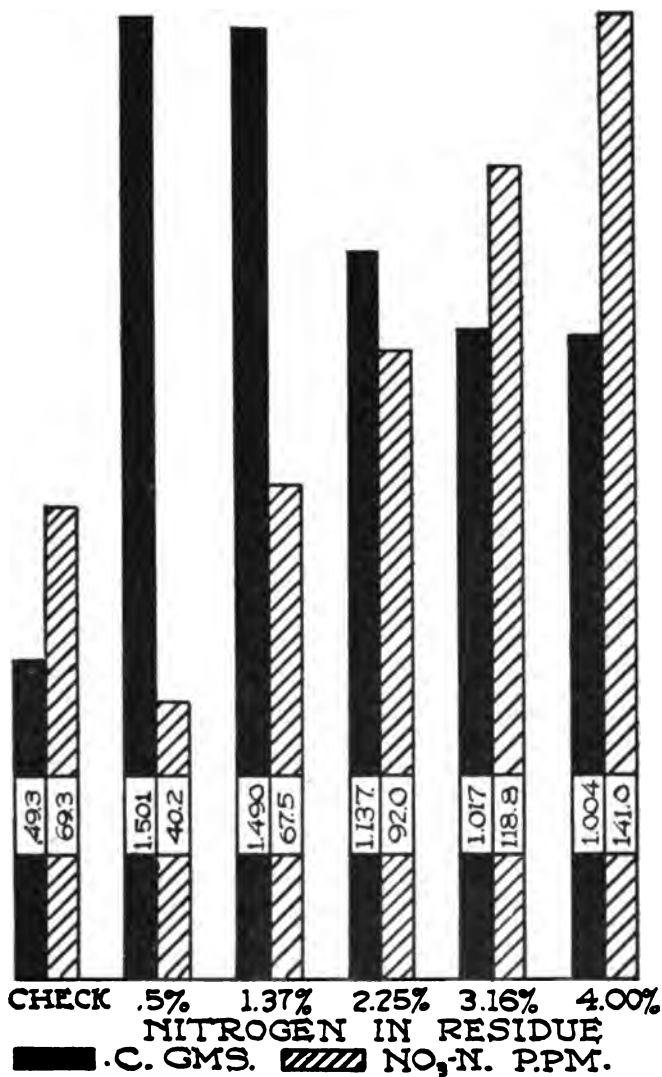


Fig. 20. A graphic representation of data in Table 19, showing the carbon dioxide evolution and nitrate-nitrogen accumulation in soil as affected by the application of residues varying in nitrogen content. Note the heavy losses of carbon in cases where low nitrogen-containing residues were applied.

application of straw or strawy manure in moderate amounts due to the fact that practically no humus was developed. In contrast to this, the growing of a legume crop for only a few years will generally benefit the physical condition of the soil, so decidedly that its effects are felt for several years.

The results in Tables 15 and 16 show also that the presence of straw inhibits nitrate accumulation and that this inhibition can be overcome by supplementing the straw with vetch, a material high in nitrogen.

The amount of high nitrogen containing crop residue that needs to be used as a supplement to straw may vary for the same soil under different seasonal conditions. But for the purpose of continuous cropping, in this case at least, it appears that the material applied should contain not less than 2.25 per cent of nitrogen (Tables 18 and 19) before very much humus will be formed and in order that the depressing effect of the straw on nitrate accumulation may be entirely overcome during one growing season.

When crop residues or strawy manures which have a low nitrogen content are to be returned to the soil they must either be allowed to decay partly in the pile, or otherwise be supplemented by a high nitrogen-containing residue in order that the percentage of nitrogen in the resulting material may reach the point where the desired nitrification for successful crop production will take place. If this is not done, summer-fallowing must be practiced, in which case there is practically no accumulation of organic matter and consequently no benefit to the soil. It is very apparent that soil organic matter cannot be maintained to any considerable extent under these climatic conditions, through the use of straw. This is especially true if straw is used on soils already low in active organic matter. The benefits derived from the amount of nitrogen returned in the straw, which has been found to be equivalent to about 10 pounds per ton of material, are more than overcome by the loss through soil leaching as a result of this summer-fallow tillage. These losses have been calculated to run as high as 18 pounds of nitrogen per acre annually.

Organic Matter Maintenance Through Use of Manure.

On experimental plots, on the station farm, where composted manure of a high grade was used for eighteen years (Table 20) in heavy applications (ten tons per acre annually) the carbon and nitrogen content of the soil was maintained.

TABLE 20.—EFFECT OF MANURE APPLICATIONS ON THE NITROGEN AND CARBON CONTENT OF PALOUSE SILT LOAM. EIGHTEEN YEARS RESULTS

Treatment	Nitrogen (N) %	Carbon (C) %	Ratio (N-C)
10 tons plowed under each fall and cropped to winter wheat annually	.207	2.64	1-12.7
10 tons plowed under each spring and cropped to spring wheat annually	.183	2.08	1-11.3
No manure, continuous winter wheat	.126	1.45	1-11.5
10 tons plowed under in spring of summer-fallow year, winter wheat every other year	.143	1.87	1-13.2
10 tons top dressed in spring on summer-fallow, winter wheat every other year	.176	1.90	1-10.8
10 tons top dressed in fall on summer-fallow winter wheat every other year	.126	1.38	1-10.9
No manure, winter wheat alternated with summer-fallow	.127	1.38	1-10.8
Virgin soil	.202	2.59	1-12.8

These results, although interesting from an experimental standpoint, require manure in such enormous amounts that the practice cannot be recommended. It should be borne in mind also that the kind of manure used here contains between $2\frac{1}{2}$ and 3 per cent of nitrogen on a dry basis,—thus making it comparable in composition to legume residues from which similar results were obtained in the plant house. (Tables 18 and 19).

Organic Matter Maintenance Affected by Soil Composition

When soils are still fairly well supplied with humus, and therefore high in their nitrogen content, as is true on the north slopes (11) and for all virgin soils, the low nitrogen containing residues like straw can be utilized with less difficulty. (Table 21).

TABLE 21.—THE DEPRESSING EFFECT OF STRAW APPLICATIONS ON THE RATE OF NITRATE-NITROGEN ACCUMULATION IN SOILS OF VARYING NITROGEN CONTENT

Treatment	Nitrogen in soils	Rate of Nitrate-Nitrogen Accumulation									
		%	5 da. p.p.m.	12da. p.p.m.	19 da. p.p.m.	26da. p.p.m.	42da. p.p.m.	67da. p.p.m.	99da. p.p.m.	124da. p.p.m.	
HILLTOP											
Check		.121	2.6	9.1	10.9	16.2	21.1	26.4	34.5	37.7	
3600 gms. Soil											
1.87 gms Straw		.121	1.7	4.7	7.2	11.7	17.5	26.4	28.2	31.4	
3600 gms. Soil											
3.75 gms. Straw		.121	1.2	2.2	4.2	10.1	11.4	23.2	22.6	27.7	
3600 gms. Soil											
7.5 gms. Straw		.121	.9	1.3	1.2	6.6	6.9	9.8	22.1	30.9	
3600 gms. Soil											
15 gms. Straw		.121	.6	1.3	1.2	2.8	4.4	6.1	10.9	10.6	
NORTH SLOPE											
Check		.150	5.0	24.6	23.0	32.7	36.1	40.2	56.5	58.3	
3600 gms. Soil											
1.87 gms. Straw		.150	5.0	13.7	15.2	18.8	23.4	26.5	35.0	36.3	
3600 gms. Soil											
3.75 gms. Straw		.150	4.0	10.8	10.9	14.9	15.5	19.4	32.4	43.5	
3600 gms. Soil											
7.5 gms. Straw		.150	2.3	3.0	2.8	8.3	11.0	14.5	26.2	27.9	
3600 gms. Soil											
15 gms. Straw		.150	1.0	1.3	1.1	2.4	4.0	5.3	15.2	20.1	

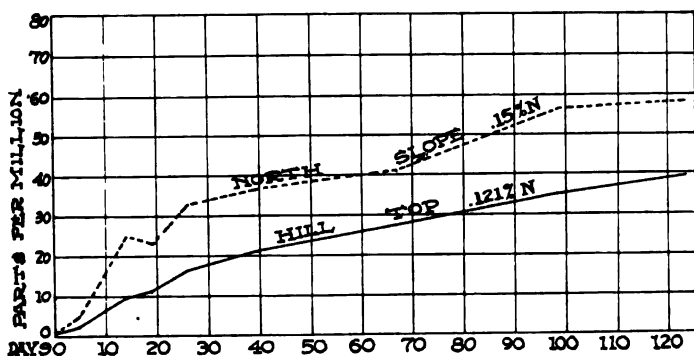


Fig. 21. A graphic representation of data in Table 21, showing the nitrate-nitrogen accumulation in Palouse silt loam as affected by high and low nitrogen content of the soil.

No doubt the large amount of readily nitrifiable material still present on the north slope has here the same beneficial effect on the decomposition as would have been obtained if the straw had been supplemented with a high nitrogen-containing residue and applied to hill top soil.

Soils still high in their nitrogen content and consequently having a wide nitrogen-carbon ratio like those found on the north slopes can utilize straw or crop residues having a low nitrogen content to much better advantage than soils from the hill tops where this ratio is narrower. Organic matter applied to hill tops to improve their physical condition should have a high nitrogen content. Well-rotted manure should be used here, while on the north slopes, which are still high in organic matter, straw may still be utilized. In extreme cases it may even be justifiable to increase the nitrogen content of soils through the use of commercial fertilizers (28) in order that straw may be returned to good advantage. All experimental data as well as results from farm experience point to one conclusion. It becomes increasingly more difficult to maintain the nitrogen and organic matter in the soil as the soil becomes more and more depleted of its virgin nitrogen and organic matter. These can be maintained and provision should be made for such maintenance at this time.

Organic Matter Maintenance Through Use of Legumes.

The amount of manure produced per farm in this region is very limited and of poor quality, and the difficulties experienced in returning straw are so pronounced that over 90 per cent of the area must depend on some other means for maintaining the organic matter.

It has been shown that the summer-fallow system exhausts the soil and therefore can not be depended upon to maintain yields. A crop that can be substituted satisfactorily for summer-fallow should tend to maintain the soil productivity; should assure a satisfactory yield of the succeeding crop; and should produce a profitable yield itself.

The data obtained where legumes were grown, as contrasted to clean cultivation (Table 22) show that these crops tend to maintain the nitrogen and organic carbon (38) in the soil.

TABLE 22.—EFFECT OF LEGUME CROPS ON NITROGEN AND ORGANIC MATTER IN SOILS

Depth of Sample	Location	Treatment	Nitrogen	Organic Carbon
Ft.			%	%
4	Pullman	Orchard soil, clean cultivated 18 yrs., and alfalfa 12 yrs.	.081	.872
4	Pullman	Control, clean cultivated 30 yrs.	.042	.429
		Difference	.039	.443
3	Pullman	Orchard soil, clean cultivated 27 yrs., Vetch 3 yrs.	.091	1.02
3	Pullman	Control clean cultivated 30 yrs.	.082	.80
		Difference	.009	.22
.5	Pullman	Wheat 18 yrs., Summer-fallow 13 yrs., Alfalfa 9 yrs.	.2188	
.5	Pullman	Wheat 20 yrs., Summer-fallow 20 yrs.	.1675	
		Difference	.0513	

In the orchard only the first cutting of alfalfa and none of the vetch was harvested. On the wheat land the alfalfa was all harvested as hay. It should be noted that the bene-

ficial effect was very pronounced in all cases where legumes were grown.

TABLE 23.—PEAS COMPARED WITH SUMMER-FALLOW AND WITH WHEAT IN THEIR EFFECT ON THE SUCCEEDING WHEAT CROP (3 years average)

	1912	1914	1916	Average
	Bu.	Bu.	Bu.	Bu.
Early fallow	26.1	50.3	47.6	41.3
Late fallow	27.2	37.5	31.6	32.1
Wheat continuously	21.4	20.2	20.5	20.7
Peas	35.0	33.7	47.0	38.6



Fig. 22. Continuous cropping is profitable when legumes are grown in rotation with small grain.

1. Continuous wheat, yield 20.5 bu. per acre.
2. Wheat following peas, yield 47.0 bu. per acre.
3. Disked early spring and plowed late spring (average summer-fallow), 31.5 bu. per acre.

Although the early fallow produces better yields than the land cropped to peas, nevertheless, due to a lack of time for this kind of tillage in the spring season, the average farmer cannot complete his plowing until so late that the fallow conditions approach more nearly what is here indicated as late fallow. It is safe to conclude, therefore, that this entire section will produce a better crop (16) following a legume, like peas, (27) than following the average summer-fallow.

Eventually as soils become more and more depleted as a result of the summer-fallow tillage, what is now considered average summer-fallow will no longer produce as satisfactory yields. The selection of a proper legume from the standpoint of a profitable crop can be made from the following: alfalfa (35), sweet clover, red clover, peas, (32), and vetch. All of these may be grown successfully, the choice depending upon the manner of utilizing the crop as well as on its better adapt-

ability to soil, climatic and topographical variations within this area.

In a location where the rainfall is more limited, and the crop is to be consumed on the farm either as pasture or hay, sweet clover may be more satisfactory than red clover. Where the rainfall is heavier alfalfa and red clover possibly should have first consideration. Alfalfa is best suited for market hay production while red clover (35) is preferred from the standpoint of a more satisfactory rotation crop. Peas, although especially well adapted as a seed crop to certain localized areas, in general have their greatest possibilities when used as a nurse crop for other legumes. Experience has shown that the cereals cannot be used successfully as a nurse crop because of the extremely dry climate during the latter portion of the growing season.



Fig. 23. Alfalfa and other legumes can be grown successfully. Most of this alfalfa field produced at the rate of four tons of high grade hay per acre in the first cutting.

Peas rarely fail in this respect. Good stands of the legumes on the rotation plots, especially of alfalfa and sweet clover were just as sure when seeded with peas as a nurse crop as when seeded alone. In extremely dry seasons it may become necessary to harvest the pea nurse crop earlier and utilize it for hay, a purpose for which it is excellently adapted, in order that the

new seeding may not be caused to suffer unnecessarily. Vetch although satisfactory from the standpoint of maintaining soil nitrogen and assuring a profitable succeeding crop, is handicapped in that it readily tends to become a weed and that it is not a profitable crop in itself.

Although the legumes listed above are all well adapted to the climatic conditions existing here, it is very apparent that the soil conditions offer decided limitations when these crops are first introduced. These limitations will become more pronounced as the introduction of legumes is delayed and the soil organic matter becomes more depleted. Best yields cannot be obtained from alfalfa, sweet clover, and red clover, under average seasonal conditions unless the soil has been treated with sulphur, used either in the form of gypsum or sulphur flour. If these materials are applied at the time when the legume is first seeded, pronounced increases in yield, frequently as high as 200 per cent are immediately obtained.

It is very evident that sulphur has a residual effect which produces satisfactory results for at least three years.

In the case where clover was grown in the plant house there was a decided increase not only in yield but also in the nitrogen content of the hay produced in every case where the soil was treated with a compound containing sulphur. In contrast, a non-legume did not respond to sulphur applications but like wheat, made its best yield and produced grain of higher nitrogen content where nitrates were applied.

While the latter emphasizes the fact that soil nitrogen and not sulphur is limiting production the former indicates that sulphur used on legumes has a stimulating effect on factors in the soil that are active in supplying such crops with more nitrogen and in getting the plant well established.

Soil stimulants, in general, should be introduced with care, because frequently their use produces increases in yield at the expense of permanent agriculture. This is especially true in regions where these stimulants are applied to make soil plant food available and where the rainfall is sufficiently heavy to cause leaching. In Eastern Washington, however, where gypsum is recommended to make profitable the growing of legumes

TABLE 24.—EFFECT OF 200 LBS. OF GYPSUM PER ACRE ON THE YIELD OF ALFALFA HAY (10% Moisture) THE THIRD YEAR AFTER APPLICATION

	First cutting	Second cutting	Annual yield
	Tons	Tons	Tons
Check	1.584	.535	2.119
Gypsum	4.400	1.855	6.255
Percentage increase			195.1

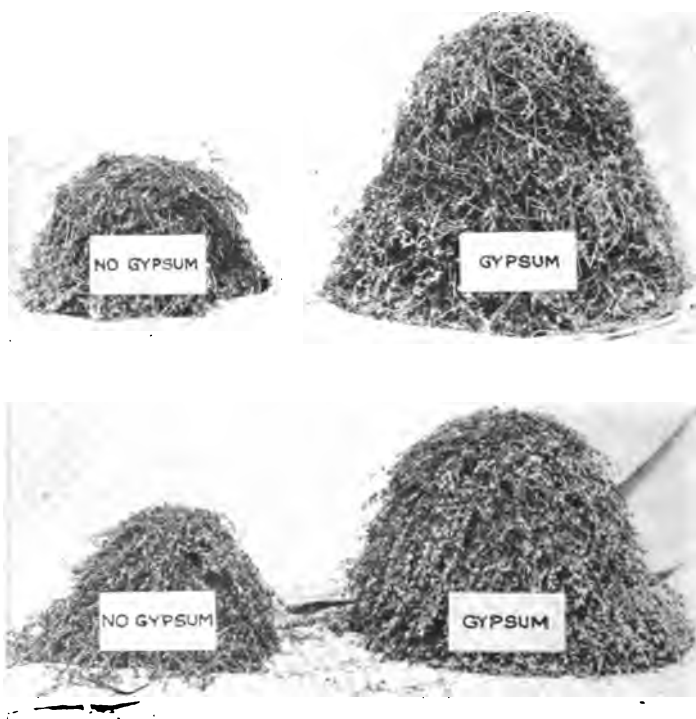


Fig. 24. Yield of alfalfa the third year after gypsum was applied at the rate of 200 pounds per acre.

First cutting (above) treated 4.400 tons per acre, untreated 1.584 tons per acre.

Second cutting (below) treated 1.855 tons per acre, untreated .535 tons per acre.

and thus leads the way to a continuous system of cropping under conditions where leaching is impossible and where the pres-

ent limiting factor, nitrogen, is overcome, there can be nothing but benefit derived from the use of sulphur in some form. Although experimental results are not available it is entirely possible that the initial application of sulphur may be sufficiently permanent in its desirable effect on legume culture to make all future applications unnecessary.

MANAGEMENT OF LEGUME SOD

That the soil nitrogen can be maintained (Table 22) through the introduction of satisfactory legumes in a rotation system, that such legumes provide the conditions essential for a satisfactory (Table 23) succeeding crop, and that they are a successful crop in themselves, (Table 24) has been shown. Rotation systems in general provide for the growing of an intertilled crop like corn or potatoes following the legumes because these crops have the adaptability to adjust themselves to best advantage to the large amounts of nitrogen made available by the tillage practiced. The conservation of moisture near the surface of the soil affected by the intertillage required by these crops results in an excessive nitrate (21) (22) development. In regions where corn is climatically well adapted and draws heavily on the soil nitrates and where the rainfall is sufficiently heavy to cause soil leaching, a high percentage of these nitrates are removed. This makes it comparatively safe to grow a grain crop succeeding the intertilled crop without danger of lodging. In this region, however, the rainfall is so limited that there is no soil leaching where a system of continuous cropping is practiced. The result is that the nitrates developed, in excess of those that have been used by the intertilled crop, are carried over in the soil, and lodging or "burning" of the succeeding grain crop is almost sure to follow. If legumes are grown in sufficient acreage to maintain the soil nitrogen supply on the farm, they are followed to best advantage by either spring or winter grain, for the reasons that lodging and "burning" can be more early controlled. Besides this, the small grains are so well adapted to both climate and topography that there should be no attempt to displace them by any intertilled crop.

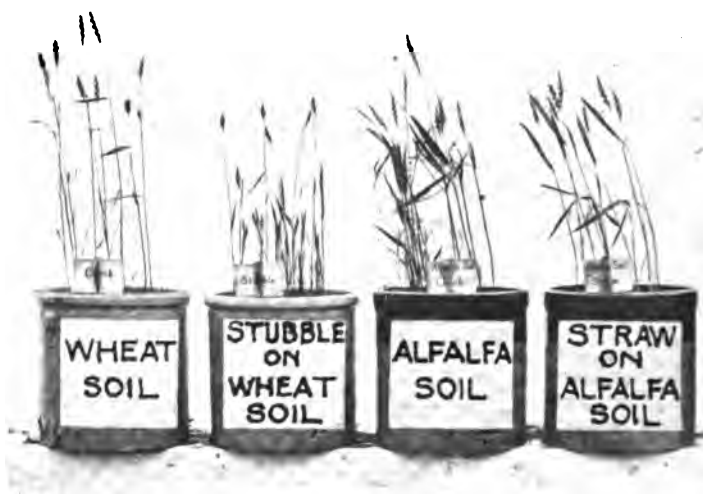


Fig. 25. The high nitrate content commonly found in alfalfa land soils when these are first broken up tends to promote excessive tillering and luxuriant development of the wheat plant, which may result in "burning" or lodging. An application of straw to such soils will check nitrate development and thus largely eliminate such difficulty.

1. Check. 2. Stubble returned. 3. Alfalfa soil untreated. 4. Alfalfa soil treated with straw.

There are occasional seasons, however, when conditions are exceedingly favorable for organic decomposition or nitrification (43) (25) because of the early fall and late spring rains. It is then that small grain immediately following a legume crop will also tend to "burn" or lodge, because of the excessive nitrate content (19) of the soil during the tillering stage. This has been one of the draw-backs to the displacing of summer-fallow with a system of continuous cropping including a legume. To justify the general adoption of such a system it must attempt to regulate the nitrate development so that there is no danger of such losses in yield.

Under the heading of "Organic Matter Maintenance through the Use of Straw" it was pointed out that whenever straw was

added to the soil there was an immediate depression in nitrate accumulation. The data presented in Table 25 shows that the

TABLE 25.—STRAW AS A CONTROL IN NITRATE ACCUMULATION (Silt Loam Soil in Two-Gallon Jars)

Treatment	NITRATE-NITROGEN (N)		
	June 22	Nov. 9	Difference
	p.p.m.	p.p.m.	p.p.m.
Wheat land soil	11.3	52.6	41.3
Wheat land soil 20 gms. straw	11.3	20.6	9.3
Alfalfa land soil	.7	81.3	80.6
Alfalfa land soil 20 gms. straw	.7	43.4	42.7

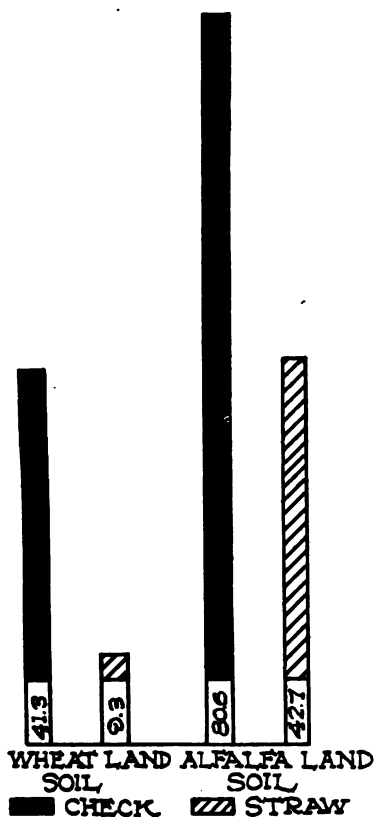


Fig. 26. A graphic representation of data in Table 25, showing the accumulation of nitrate-nitrogen in p.p.m. as affected by applications of straw on wheat and alfalfa land soils. Note the depressing effect of straw which may serve advantageously in controlling excessive nitrate accumulation.

nitrate accumulation on straw-treated alfalfa field soil was held down to where it compared favorably with the nitrates found under good summer-fallow conditions on untreated wheat field soil. The nitrates present in each case were sufficient to satisfy the demands of a good crop and still not so high as to cause the excessive tillering previously discussed.

The results here are consistent with field experience. Where straw is applied to alfalfa field soil in preparing it for the first crop of grain, the tillering can be kept within those limits where lodging or "burning" will be avoided. Experimental data from field plots, although limited, show that straw used at the rate of about one and a half tons per acre will affect this control. Besides this there are indications of other benefits derived from the use of straw which are less apparent but equally important. Some of these are: (1) it distributes the beneficial residual effect resulting from the growing of legumes; (2) it causes a decomposition that is more effective from the standpoint of the maintenance of organic matter in the soil, and (3) it offers an opportunity for the return to the soil of the plant food contained in the straw without causing any depressing effect on the yield of the following grain crop.

CROP ROTATION

The introduction of a crop rotation system is impracticable except under conditions where the precipitation is sufficient to grow profitable crops (23) annually. Experiences as well as experimental data on water requirements of plants (41) indicates that continuous cropping is impossible in that portion of Eastern Washington receiving less than 18 inches (7) of precipitation annually. This area, therefore, must depend on a summer-fallow system such as is discussed under the heading, "Effective Summer-Fallow," and also covered in more detail in Bulletin 164 of the Washington Experiment Station. At present there is no known means of profitably maintaining the soil fertility and the region is confronted with a gradual decline in yield consistent with soil depletion. This decline will

continue until a stage is reached where the nitrogen available for crop production is equivalent to that supplied by free fixation and carried down by precipitation.

Where the annual precipitation exceeds eighteen inches, crop rotations are possible. The rotation selected, besides including crops that can be grown at a profit, and that are adapted to climate and topography, must provide for the maintenance of the soil's nitrogen supply. The small grains, especially wheat, barley and oats, satisfy all but the latter requirement and this was a matter of small concern in the past when the soil was still well supplied with virgin plant food. This requirement now, however, has become the limiting factor in the production of small grains, and the growing of legumes is a necessity. It has been shown that alfalfa, sweet clover, red clover, and peas are well adapted and profitable and therefore, should be fitted into a rotation with sufficient prominence to displace summer-fallow. The organic matter incorporated in the soil as the result of growing legume crops is very active in that it decomposes readily and furnishes an adequate nitrate supply (32) for the succeeding wheat crop. This cropping plan, if followed, will maintain the acreage at present devoted to small grain and at the same time produce a higher yield and better quality of product. Natural variations within the area as well as individual preference make it inadvisable if not impossible to recommend a rotation system that can be generally followed.

Be the selection of crops what it may as regards kinds and varieties of small grains and legumes, the following points should be borne in mind.

Small grain should be grown about 50 per cent of the time.

Alfalfa should ordinarily not be grown for more than about five successive years in order to build up the soil sufficiently to make it possible to grow five consecutive crops of small grains. The basis for this is the generally accepted fact that the amount of nitrogen fixed annually by a legume becomes less the longer the land is devoted to such crop.

The hill tops are in greater need of the benefits derived from legumes than the slopes.

Red clover and sweet clover are better suited to short rotations than alfalfa.

Peas although exceptionally well adapted to some localities have their greatest value in general as a nurse crop for other legumes.

The desirable physical condition of the soil resulting from the growing of legumes will make unnecessary much of the tillage ordinarily required in the preparation of a seed bed for small grain. In the case of alfalfa, for instance, it is probable that disking may be substituted for plowing for the first few years after the sod has been broken.

If intertilled crops like corn or potatoes are to be introduced they should not immediately follow the legume.

Legumes, due to the fact that they need inoculation, rarely produce maximum returns the first time they appear in the rotation.

Sulphur either in the form of gypsum or elemental sulphur should be applied when legumes are seeded for the first time. This applies especially to alfalfa, sweet clover and red clover.

DRAINAGE

Many of the valleys, so numerous in this region, are very poorly drained, causing them to be left in permanent meadow. These low lands, which are unquestionably the most fertile in the entire area, not only produce unprofitable crops but interfere very decidedly with field operation. All these valleys have a well defined course and outlet and can be artificially drained without difficulty.

The natural increase in the value of land augmented by the greater producing power of the soil resulting from the rotations recommended focuses attention on the reclamation of these low lands.

SUMMARY AND CONCLUSIONS

All conclusions reached here regarding tillage, and utilization of straw and manure apply to silt loam soils of Eastern

Washington receiving more than fifteen inches of precipitation per annum, but those conclusions pertaining to continuous cropping and the growing of legumes apply only to that portion of the area receiving more than eighteen inches.

1. Practically all the precipitation comes in the form of gentle rains during the fall, winter and the early spring.

2. The relative humidity during the growing season is very low, thus causing excessive evaporation and decided ranges in day and night temperature.

3. Palouse silt loams are fertile as compared to many of the representative silt loam soils in the United States.

4. Small grain (wheat, barley and oats) with the land in summer-fallow every second or third year, constitutes the cropping system generally practiced.

5. Available nitrogen and not moisture is the limiting factor in crop production.

6. Summer-fallow tillage is practiced to make nitrogen available for the next crop.

7. The most effective summer-fallow tillage is that which keeps the highest amount of moisture in the surface foot of soil for the greatest length of time during the summer-fallow year.

8. The tillage subsequent to spring plowing and harrowing on summer-fallow should be of such nature and frequency as to control weed growth most economically.

9. Corn or any other intertilled crop, when substituted for summer-fallow, does not materially reduce the yield of the succeeding grain crop.

10. The amount of tillering of small grain is directly affected by the amount of nitrate nitrogen in the surface soil during the tillering stage.

11. The rate of seeding winter grain should be influenced by the nitrate content of the soil and the time available for tillering, a high nitrate content and early seeding requiring a lesser rate.

12. Lodging and "burning" of winter wheat can in part be controlled by a lighter rate of seeding.

13. The value of summer-fallow tillage is most pronounced when winter grain is seeded sufficiently early to allow time for tillering.

14. The quality of wheat is directly affected by the nitrate content of the soil, irrespective of variety.

15. During thirty-nine years of cropping 22.1 per cent of the nitrogen and 34.5 per cent of the organic matter has been lost from the soil.

16. The loss of nitrogen from the soil is not nearly all accounted for in the crops removed.

17. The moisture conserved by summer-fallowing has been sufficient to make soil leaching possible, which resulted in the loss of large amounts of plant food.

18. The dry summers make it difficult for straw or other low nitrogen-containing organic materials to decompose in the soil unless summer-fallowing is practiced.

19. The rapid destruction of soil organic matter affected by summer-fallow tillage is producing a poor physical condition of the soil.

20. The return of straw to the soil has a depressing effect on nitrate accumulation and consequently on yield.

21. The depressing effect of straw and other crop residues is most pronounced when the nitrogen content of such materials is less than 2.25 per cent.

22. The depressing effect on nitrate accumulation is most pronounced on soils low in nitrogen and organic matter.

23. Fresh strawy manure, when applied to the soil, has practically the same depressing effect on nitrate accumulation as straw.

24. The amount of nitrates accumulated in the soil, when residues are applied, is dependent upon the nitrogen content of the residue, the nitrogen content of the soil and the time available for nitrification.

25. Soil organic matter can not be as rapidly increased by the addition of low nitrogen-carrying residues, as by those materials that have a higher nitrogen content.

26. Straw and strawy manure in themselves are limited in their value for organic matter maintenance. The amount of manure produced in the region, even if conserved, is at present so limited that it plays an insignificant part in the maintenance of soil fertility and organic matter.

27. The difficulty of maintaining the soil organic matter becomes more pronounced as the soils become more depleted.

28. Legume crops tend to maintain the soil nitrogen and organic matter.

29. Alfalfa, red clover and sweet clover, peas and vetch are legumes that can be grown successfully.

30. A legume crop introduced in place of a summer-fallow will benefit the succeeding grain crop as much as average summer-fallow tillage.

31. Peas are an excellent nurse crop for alfalfa, red clover, and sweet clover.

32. Legumes, especially alfalfa, red clover and sweet clover, when first introduced, will respond to a soil treatment with gypsum or elemental sulphur and such treatment is recommended.

33. Summer-fallow is unnecessary where the annual rainfall is 18 inches or above provided legumes or intertilled crops are grown in rotation.

34. To avoid danger of lodging or "burning" of a grain crop when grown on a legume sod, straw should be applied when the sod is first plowed up.

35. Legumes should be followed by small grain in preference to an intertilled crop in the rotation system.

36. Under a continuous cropping system small grain due to its excellent adaptation should be grown about 50 per cent of the time.

37. No continuous cropping system can be recommended for that portion of the area where the annual precipitation is less than 18 inches.

38. Land drainage is badly needed in many of the valleys and should receive foremost consideration.

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STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIRECTOR'S OFFICE

THIRTY-FIRST ANNUAL
REPORT

For the Year Ending June 30, 1921

BULLETIN No. 167

January, 1922

All bulletins of this station are sent free to citizens of the state on
application to the Director

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*In co-operation with the United States Department of Agriculture.

**In co-operation with Chelan County.

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PUBLICATIONS

The following publications were prepared by members of the Experiment Station Staff and published during the year:

General Bulletins

- 156 A Study of Goltre and Associated Conditions in Domestic Animals, by Dr. J. W. Kalkus.
- 157 Pea Straw for Fattening Beef Cattle, by H. Hackedorn and J. Sotola.
- 158 Thirtieth Annual Report.
- 159 Wheat Production as Influenced by Variety, Time of Seeding and Source of Seed, by E. G. Schafer, E. F. Gaines and O. E. Barbee.
- 160 Cultural Experiments with Wheat, by E. G. Schafer, E. F. Gaines and O. E. Barbee.
- 161 Studies on Digestibility of Sunflower Silage Fed to Sheep, by J. Sotola.
- 162 Sunflower Production for Silage, by E. G. Schafer and R. O. Westley.
- 163 Studies in Apple Pollination, by O. M. Morris.
- 164 Investigations in Dry Farm Tillage, by M. A. McCall and Henry F. Holtz.
- 165 An Investigation of Sulphur as a Plant Food, by Geo. A. Olson and J. L. St. John.

Pullman, Washington,
January 15, 1922.

Honorable Louis F. Hart, Governor,
Olympia, Wash.

Sir:—

Pursuant to the act of Congress, March 2, 1887, relating to the establishment of agricultural experiment stations, I have the honor to transmit herewith a report of the activities of the Washington Agricultural Experiment Station for the last year. Because of the nature of some of the work, the report in part covers the activities from November 1, 1920, to October 31, 1921, rather than the fiscal year July 1 to June 30. The context indicates where this is the case.

Suggestions as to some of the needs of the Experiment Station and a financial statement also are included.

Very respectfully,

EDWARD C. JOHNSON,
Director.

Thirty-First Annual Report, Washington Agricultural Experiment Station

DIRECTOR'S STATEMENT

Introduction

The State of Washington has a greater diversity of climate and topography than any other state with the possible exception of California. With rainfall varying from six inches a year in the south central part to over one hundred in places on the Pacific slope; with soil conditions varying from the rain-leached lands of parts of western Washington to the sun-parched deserts of the dry belt; with soils as different in agricultural possibilities as volcanic ash, glacial gravel, alluvium, residual disintegration, bogs and tide lands; with natural vegetation ranging from sage brush to the densest forests; with temperature as diverse as the equable climate along the coast and the marked summers and winters in the inland country; and with marketing problems due to large distances from centers of population. Washington presents to its farmers who already are using 13,244,720 of its 42,775,040 acres, a vast variety of problems, many of them only partially solved and a host not understood at all.

The Washington State Experiment Station is now working on some of these problems and has rendered distinguished service in many fields. The development of high-yielding varieties of wheats, notably Hybrid 128 from a cross made in 1899, distributed to farmers in 1909, now grown on over 400,000 acres or 1/10 of the wheat area of the state, averaging 6.8 more bushels per acre than wheats ordinarily grown and increasing the yield for the state over 2,700,000 bushels in 1921; the selection of cereal varieties adapted to the different sections of the state; the improvement of tillage methods; the demonstration of the value

of sulphur as a plant food; the improvement in seed treatment practices for the control of smut in wheat; the working out of the life history of the codling moth for Washington state; the perfection of the lime sulfur spray and the improvements in spraying practice which have helped to place the great horticultural industry of Washington in the first rank among all the states; and the demonstrations of the use of iodine in the control of goitre in domestic animals, are but a few outstanding examples of this large service.

The list of publications of the Washington Experiment Station found on pages 60 to 64 illustrates the multiplicity of helpful studies and the contributions to knowledge which the station has made and the divisional reports herein show the consistent progress in the many investigations now under way.

Because of the recognition of the value of the work of the station there is now an ever increasing demand for more investigations of the state's many agricultural problems. With new orchards coming into bearing; with farm lands in the older cultivated sections being cropped of their fertility; with new crop pests and diseases appearing; with the need for diversification; with the problems of land reclamation and the development of marginal lands; with the necessity of greater utilization of by-products of the farm and with the ever increasing complexity in marketing farm products, this demand is natural and a recognition of the source from which help is confidently expected.

Furthermore, with a valuation of \$1,057,429,848 for all the farm property in the state and with a total valuation of \$296,660,990 for all the farm products produced in 1919, it is increasingly realized that the agricultural industry of Washington is not only its most essential but also the largest of all its industries. Lumbering, the only other industry approaching agriculture in magnitude, had an output valued at \$220,512,000 for the same year*

*The prices existing at the time of taking the census of 1920, from which these figures are derived, were almost at the peak, yet they furnish a comparatively fair basis for comparison.

By standing ready to help solve the problems of this great industry the Experiment Station is in a position to render service to the state measurable by many times whatever support it receives. Funds appropriated for its work and economically and efficiently used are a capital investment bearing high returns. Opportunity for such investments must not be permitted to pass by even in strenuous times.

Investigations in Co-operation with the U. S. Department of Agriculture

The investigations in forage crop production conducted in co-operation with the Office of Forage Crop Investigations of the U. S. Department of Agriculture, were continued as heretofore at the main station at Pullman, the Adams Branch Station at Lind and the Branch Station at Waterville.

Co-operative work in cereal investigations at the Adams Branch Station was terminated by the U. S. Department of Agriculture, due to a shortage of funds, in September, 1920. The co-operative work in breeding wheat for smut resistance at the main station at Pullman was continued without change, and additional co-operative investigations of the foot-rot of wheat commenced.

Co-operation with the Bureau of Entomology in wire worm investigations commenced two years ago was continued by the Bureau of Entomology but the assistance rendered by the Washington Experiment Station because of shortage of funds was decreased in amount. The work was done in the Adams County area primarily, with headquarters at Lind and Ritzville.

Co-operation with the Office of Horticultural Investigations, U. S. Department of Agriculture, relative to seed potato production was continued as in the previous year, the work being done at Pullman, at the Irrigation Station at Prosser and in co-operation with farmers.

Co-operation with the Office of Farm Management of the U. S. Department of Agriculture and with the University of Idaho in investigations in the cost of producing wheat

and organization of wheat farms was continued. Co-operative work with the Office of Farm Management in a study of logged-off lands in Western Washington was commenced and the field work in a survey of 250 farms completed.

Co-operation with Chelan County in cover crop and soil investigations in the orchards of that section was continued, Chelan County paying the entire salary of the investigator and all of the expenses involved, the station furnishing the supervision and direction of the work.

Co-operation with the Bureau of Markets of the U. S. Department of Agriculture in market investigations was continued until the Office of Farm Markets by legislative enactment was transferred to the Department of Agriculture at Olympia, April 10, 1921.

Changes in Staff

There were few changes in the staff during the year. The following resignations and appointments became effective:

Resignations—

George A. Olsen, head of the Division of Chemistry and State Chemist, May 1, 1921.

Fred S. Martin, Acting Supt. Official Testing, Mch., 1920.

Appointments—

J. L. St. John promoted to Acting Head of the Division of Chemistry and Acting State Chemist, May, 1921.

Otto McCreary, Assistant Chemist, September, 1920.

Legislation Affecting the Experiment Station

The adoption of the administrative code by the legislature consolidating the numerous boards, commissions and offices of the state government into ten executive departments, responsible to the Governor, removed from the State College and Experiment Station the Office of Farm Markets and discontinued the State Board of Agriculture of which

the Director of the Experiment Station was ex-officio a member.

A special appropriation was made by the Legislature for buildings to replace those destroyed by the tornado in July, 1920.

Buildings and Land

Building plans for a complete poultry plant to replace the old plant partly destroyed by the tornado were drawn and construction commenced. This plant is to include a colony laying house 24 x 30, a breeding and laying house 16 x 196, a brooder house 16 x 120, two colony brooder houses 16 x 24, a two-story incubator house 38 x 60' and a two-story feed house 30 x 40.

While this plant is primarily for instructional work in the College of Agriculture, it will also provide facilities for experimental work in incubation and brooding and more especially in breeding. The long breeding house was designed primarily for investigational work.*

Construction of beef cattle and sheep barns was postponed until 1922 because of the continued high cost of labor and materials. They will be built early the coming year and will be of great help to the experimental work with beef cattle, sheep and hogs.

Needed improvements were made around the old cattle barns to provide adequate drainage. Further improvements will be made in them to fit them for the dairy cattle herd as soon as the new beef cattle and sheep barns have been constructed and the space now occupied by beef cattle and sheep vacated for the dairy cattle.

Additional greenhouse space is essential for the Division of Plant Pathology, Bacteriology, Chemistry and Soils.

At the Irrigation Branch Station at Prosser, much additional farm equipment such as grain binder, corn harvester, silage cutter, manure spreader, etc., was purchased. A silo 14 x 42½ feet and six individual hog houses were con-

*These buildings were erected and in use November 1, 1921.

structed and considerable fencing for pasture for hogs and cattle was done. There is real need that a building program be undertaken at this station providing for the construction of two additional farm cottages, a cottage for the superintendent, a laboratory and seed storage building, feeding sheds, pens and yards, an additional silo, and a dairy barn.

The Adams Branch Station at Lind is comparatively well equipped with buildings and no additions are at present contemplated. The buildings, however, should receive a coat of paint at the earliest opportunity.

No building program is contemplated at the Waterville Branch Station, which is conducted largely on rented land.

More land is urgently needed at the Experiment Station at the State College at Pullman for the growing of pure seeds for distribution to the farmers of the state. The demand for such seeds is far beyond the ability of the station to supply, and as improved varieties are secured by means of breeding and selection, this demand will become the more urgent. Land should be available for growing them in such quantities that they may be sent in small amounts to farmers desiring to use them.

In the director's report for 1920 the following paragraph occurs:

"The college farm, now consisting of about 560 acres, is used for all the experimental work and for the growing of some seed and some feed. There is always more demand for seed than can be supplied. Large quantities of feed also must be purchased each year for the stock on hand, and with the increasing herds and flocks more feed will be needed. It should not be necessary to ship this in and to pay for freight as well as feed from current appropriations. With additional land on which to increase and grow seed for distribution, the land now devoted to this purpose would be available for necessary expansion of pastures and for feed production." It is urgently recommended that provision

be made for additional land so that the needs here indicated may be provided.

Needed Additions to the Station Staff

Additions to the station staff in many instances are much needed. There should be additional specialists devoting full time to investigational work in connection with horticultural interests. With such additions, it would be possible to attack many of the urgent cultural, management, plant disease and insect problems of the large horticultural industry of this state.

Additional help for investigational work is also much needed in dairying, animal husbandry, farm crops, soils and farm management. Such help should devote full time to experiment station work so that it would be possible at any time to make the necessary trips to those sections of the state where the problems occur. In some instances very desirable help may be secured by the appointment of research assistants in the nature of graduate fellowships and scholarships. This practice not only will give much needed help in many experimental and research projects at small expense but also will give training to men needed now and in the future in experiment station and college work. It is hoped that from time to time men of means will become interested in making endowments for research fellowships and scholarships in connection with the experiment station so that many of the problems which it is not now possible to touch because of limited means increasingly may receive attention.

In addition to an enlarged staff to devote its time primarily to investigations and experimentation, increased maintenance for the various projects is essential. The needs of the various divisions of the Experiment Station are more fully stated in the divisional reports.

DIVISION OF ANIMAL HUSBANDRY

H. Hackedorn in Charge

Pea Straw for Fattening Cattle:

A summary of the investigations relative to the best method of utilizing pea straw was published during the year in Bulletin No. 157 of the regular series. Further work on this project was temporarily suspended because of the demand for information on the feeding value of sunflower silage.

Sunflower Silage for Beef Production:

A feeding trial for the purpose of comparing sunflower silage with corn silage as a feed for production of beef is being conducted with 30 steers. Two lots of fifteen head each are being fed for a period of 90 days. Linseed oil meal is fed at the rate of 2 lbs. per head daily. The silages are mixed with cut hay in the proportion of 1 part hay to 3 parts corn silage and 1 part hay to 3½ parts sunflower silage. Digestion coefficients of sunflower silage fed to steers are to be determined during the course of the sunflower silage investigations. Similar coefficients for sunflower silage for sheep have been worked out and were published in Bulletin No. 161 during the year.

Study of Comparative Value of Protein

Supplements in Swine Rations:

This work was continued without interruption. A three-to-one mixture of rolled barley and wheat shorts was used as a basal grain mixture fed to pigs in various lots. The pigs weighed from 40 to 70 lbs. at beginning of the tests and finished at weights from 150 to 170 lbs. The mixture was supplemented with tankage or fishmeal, and in one case with cocoanut meal in quantities sufficient to provide the proper nutritive ratio for pigs, as they increased in weight.

For every ration tested in dry lots a similar one, though less in quantity, was fed on alfalfa and pea forage. The comparative feeding tests in dry lot, on pea forage and on

alfalfa forage involving 25 head fed 57 days, 35 head fed 74 days and 14 head fed 65 days have failed to demonstrate any marked difference between fishmeal containing 56% protein and tankage containing 60% protein. The cocoanut meal was found to be bulky and unsatisfactory as a protein supplement, especially in rations for young pigs.

The work with fishmeal and tankage is being continued and has been expanded to include linseed meal and a mixture of equal parts of linseed meal with tankage.

Protein Supplement on Pea Forage:

To test the advisability of self-feeding tankage on pea forage, two lots of 7 pigs each were given access to areas of 2 acres of peas. Lot I had access to pea forage only, while Lot II was self fed on tankage in addition to forage.

The peas were fairly ripe July 26th when the test began. The hogs averaged about 83 lbs. at the beginning. For the total period Lot I averaged 1.529 lbs. gain per head daily, and Lot II gained 1.540 lbs. Where tankage was self-fed each pig consumed an average of 23.43 lbs. of that feed for the 60-day test. There was no apparent difference in condition of the pigs in the various lots.

The forage for Lot I made a yield of 36.3 bu. of peas per acre while that of Lot II averaged only 29.1. The pigs receiving tankage were in the low yielding lot, but made gains equal to those of the pigs in the high yielding lot.

The tankage fed pigs produced 323.5 lbs. of pork per acre with a grain requirement of 529.7 lbs. peas and 25.5 lbs. tankage for 100 lbs. gain. Pigs having access to forage produced only 321.2 lbs. of pork per acre, requiring 678.5 lbs. of peas for every 100 lbs. body gain.

The net returns per acre due to peas with pigs valued at \$8.00 per cwt. was \$25.69 for Lot I and \$23.41 for Lot II. Considering the fact that the peas for Lot II produced 7.2 bu. peas less per acre than those for Lot I the returns are exceptionally good in this instance. The tankage cut down the peas required per 100 lbs. gain more than enough to justify its use.

The only labor involved in production of feed was in preparation of the ground and in seeding. There are no charges for cutting and threshing of peas to be deducted from the returns. Furthermore, the forage not consumed as well as droppings from pigs can be turned under, a system in every way tending towards an increased soil fertility.

Needs of the Animal Husbandry Division:

More comprehensive library facilities are badly needed. This was emphasized in the last annual report.

A laboratory for investigations in animal nutrition is needed. It would not be expensive and would make possible investigations in fundamental laws of growth and in fattening and maintenance of livestock, a work involving numerous questions of a chemical nature. It would facilitate digestion trials which are so essential when feeding values of new forages and concentrates are in question. A normal increase in experimental work along nutritional lines will require the addition of a man trained for this work to the Experiment Station staff.

Some experimental work on the problem of wintering the idle as well as the growing horse is highly desirable, especially for this section of the country. It should be given early attention.

DIVISION OF BACTERIOLOGY

W. I. Nightingale in Charge

Legume Inoculation Cultures:

Inoculation of the leguminous crops is of fundamental importance to successful agriculture. As the demand for more efficient crop production becomes more pressing, inoculation gains in importance. The Bacteriology Laboratory, in co-operation with the Division of Farm Crops, has furnished to the farmers of the state this year sufficient cultures to inoculate 8325 acres. These were supplied for the

different legumes as follows: Alfalfa, 3305 acres; clover, 1151 acres; peas, 2447 acres; beans, 223 acres; vetch, 590 acres; soybeans, 47 acres, and sweet clover, 557 acres.

There is a slight decrease in the total acreage of cultures supplied over last year due to a big reduction in the acreage of peas planted in eastern Washington. However, about 200 more farms were supplied with culture than ever before, showing a general increase in the inoculation practice over the state as a whole.

Factors that Control the Infection of Legumes by Bacteria.

Work has been done to determine factors which contribute to the success or failure of legume inoculation. Some of the factors under study are moisture, temperature, number of bacteria applied to the seed, chemical constituents of the soil, virulence of the bacteria, source of the bacteria, and method of applying the bacteria to the seed. Good infection has been secured in Palouse soil containing 12% to 26% moisture. Data were secured in the field and in the greenhouse on seven common legumes inoculated with bacteria from different sources to study the effect of their virulence. In all, 34 different strains were tested. The soil, water and milk methods of applying the bacteria to the seed were used. The order of success was as in the order given with little difference in nodule formation between the soil and water methods of application. The number of bacteria applied to the seed is of marked less importance than the virulence of the bacteria on the number of nodules formed. Weight of the plants and yields have been taken and nitrogen analysis of the plants will be made to study fixation. Results so far obtained indicate the importance of the careful selection of strains of bacteria used for inoculating legumes.

The Effect of Straw on the Biological Soil Processes:

Two years' work has been done on this problem and the

results published. Long experience and experimentation have shown that the immediately succeeding crop yield of wheat on Palouse soil is reduced when the straw is not removed with the crop or is added to the soil. This is caused by the transformation of nitrogen available for plant food into a non-available form.

Straw applied to the soil stimulates reproduction of bacteria but there is no disturbance in the balance of types present. The bacteria use the straw as a source of carbon and the nitrates in the soil as a source of nitrogen. The nitrates are transformed into organic nitrogenous material and for the time being are lost as available plant food. The more straw applied the greater is the loss of nitrates.

Work is being continued in the field and in the laboratory to determine the other specific factors which affect the decomposition of straw in the soil, and to discover if possible methods of stimulating the biological flora to a more rapid and less destructive action.

Pure Culture Starters for Making Cider Vinegar:

In an effort to aid the farmer transform his cull apples into income, a campaign was started in co-operation with the Department of Horticulture, to turn the apples into vinegar. Pure culture starters, directions for their use, and a pamphlet on how to make cider vinegar were supplied to the farmers at a small charge to cover the cost of materials and postage. One hundred farmers in the state called for this service in two months. This work will be followed up, improved and enlarged upon.

Miscellaneous Analyses:

In the service work for the people of the state, thirty samples of water were analyzed for pollution and forty samples of milk and fifteen samples of food examined.

Publications:

"The Effect of Straw on the Biological Soil Processes" appeared in "Soil Science," Vol. VII, No. 111, September,

1921. "Making Cider Vinegar," a pamphlet with directions for utilizing cull apples, several letters to County Agents, and newspaper articles on legume inoculation have been distributed.

New Investigations:

Service to the Dairy Industry of the state should be increased. Investigations of the flora of soils under different systems of cropping in the dry and semi-arid sections of the state should be conducted with the view of determining the effect of different practices on soil up-building.

DIVISION OF CHEMISTRY

J. L. St. John in Charge

Sulphur as a Plant Food:

Work was resumed on the sulphur project which had been temporarily discontinued. Sulphur determinations were made on over 300 samples of plant material saved from greenhouse work in 1915, 1916, and 1917. These data together with the 1914 results and also data on the sulphur content of Palouse soils, on the effect of various fertilizers on the yield and composition of alfalfa on the college farm, on the effect of gypsum on the yield of alfalfa on Palouse farms, on the amount of sulphur brought to the land in the rain, and various other data have been correlated and are now ready for publication under the title "Investigations of Sulphur as a Plant Food."*

It has been found that the sulphur content of the soils studied is low and there is indication that the amount precipitated in the rain is small. Elemental sulphur added to soil plots have increased yields of wheat, oats, barley and peas. Gypsum, acid phosphate and sulphuric acid added to field plots have nearly doubled the yield of alfalfa. Two hundred pounds of gypsum per acre have increased farmers' yields as much as 240 per cent. It is felt that the results obtained justify further work on this very important problem.

*This has been published as bulletin No. 165 of this station.

Nutritional Studies with Wheat:

A study of wheat has been made with the object of finding means for overcoming the alleged toxicity of this cereal. It has been found that "toxicity" can be overcome and that white rats (the standard animal used in working out the principles underlying the adjustment of foods) will successfully grow and reproduce when fed a wheat ration, supplemented by protein and fat soluble **A**, if a proper adjustment of the inorganic elements calcium, chlorine and sodium is made. This has developed into a study of the limits for the need of these elements in a wheat ration and especially the limits of the sodium requirement. A paper on this subject is now ready for publication. Work on chlorine is under way. A broad basis has thus been laid in this division for a study of fundamental importance to a wheat-raising state and of fundamental importance in nutrition. The study of inorganic salts in nutrition has received far less attention than its importance deserves. The study of the relative nutritive value of wheat and flour is a subject which has received too little attention. Wheat and flour are of course eaten for the actual nutrition which they furnish, and we believe this should be one basis for their valuation. To make this basis practical it will be necessary to determine the factors which most influence the variation in nutritive value. For instance, does the variation in nitrogen play the most important role and what is the influence of variation in phosphorus, or sodium or vitamin content, etc. The relative value of whole wheat and white flour bread is a question which is receiving increasing attention and on which there seems to be too little data of a definite nature. Various questions of this character are under consideration.

Baking Qualities of Flour:

The action of enzymes on flour from various states and on gluten from these flours has been studied. The total amount of nitrogen digested, basic nitrogen, amino nitrogen

by the Sorenson formal method, and the amount of nitrogen in solution but precipitated by phosphotungstic acid have been determined on both flours and glutens. These were checked against the acid digestion in each case. The work has not yet progressed to a point where it is felt that definite conclusions are justified. A rather extended piece of preliminary work has also been carried out preparatory to the study of the hydrolysis of gluten. It is hoped that the division will be able to continue these investigations.

Conductivity Measurements:

Conductivity measurements were made on the water extract of 64 soils which have been rather extensively investigated from a chemical standpoint. With very few exceptions the conductivity of the extract from the surface foot of soil was higher than for soil from other depths. Extracts from virgin and cultivated soils show about the same conductivity. Hill top soils usually show the lower while bottom land soils show the higher conductivity.

Co-operative Study of Methods of Analysis:

Co-operative work with the Association of Official Agricultural Chemists has been continued in a study of methods for the determination of crude fibre in feeds and for the determination of fat in feeds.

Miscellaneous Work.

A large number of samples are received by the division during the year which cannot be given attention because of lack of time and funds. The division aims to be of as much service as possible to the people of the state and analyses are made in cases where the reason for making them seems to justify a use of part of the limited time available.

Various analytical work has been done for other Divisions of the Station.

A large amount of time was spent in planning and supervising the work on the new laboratories in James Wilson Hall. These were completed to a point where it was possible for the Division to move in.

State Chemist Work:

The Chemist of the Experiment Station is ex-officio State Chemist and the equivalent of time and a half for one man is required of the Division of Chemistry in the work done in co-operation with the State Department of Agriculture in enforcement of the Food, Feed, Fertilizer and Insecticide laws of the state. A large number of the samples handled are feeds and fertilizers. Comparing the samples received from the official inspectors just after the new law became operative in July, 1919, with those received now, it is gratifying to note that a very much larger percentage of such samples now conform to the requirements than formerly. The results of the work done have not been published. It is suggested that the State Department of Agriculture provide funds for such purposes in view of the fact that consumers desire first-hand information as to the nature and quality of the feeds which they purchase. Such a publication would also serve to satisfy those who in a measure doubt that the laws are being enforced. While the technical analytic work in connection with the regulatory work of the State Department of Agriculture can well be done in the laboratories of the experiment Station and it is believed that such practice insures both accuracy and economy for the state, the expense of such work undoubtedly should be borne by fees or by the State Department of Agriculture rather than by the Experiment Station as at present.

Additional Needs:

The amount of time available for co-operation with other Divisions has been limited. Co-operative work in joint projects is not only highly desirable but is essential in many cases. Additional help is needed for such work.

DIVISION OF DAIRY HUSBANDRY

E. G. Woodward in Charge

Sunflower Silage vs. Corn Silage:

Work was temporarily discontinued on this project but will be resumed during the next fiscal year.

A Study of Calf Rations:

Condensed or Semi-solid Buttermilk for Calf Feeding: Eight calves were raised on condensed buttermilk from the age of three weeks up to the age of four to six months. All made satisfactory gains ranging from 1.3 to 1.6 lbs. per day. The gains during the first two months usually were less than these figures, while at a later age the growth was more rapid. This was true also when skimmed milk was fed. The calves raised on condensed buttermilk were not troubled with scours, and in this respect the condensed buttermilk seemed to be a slightly more satisfactory feed than the skimmed milk.

In raising these calves the following practices were used: The calves were taken from their dams within 24 hours after birth and were then fed whole milk until they were two weeks old. At that time condensed buttermilk was substituted gradually for the whole milk until at the age of three weeks the calves were receiving no whole milk whatever. In making this substitution, a very small quantity of condensed buttermilk was mixed with the whole milk for two or three feedings. This was gradually increased as the calf became accustomed to the taste of the condensed buttermilk until one-half pound was fed twice a day. At that time water was gradually substituted for the whole milk, and the condensed buttermilk was increased until at the end of two or three days the calf was receiving no whole milk and was getting not in excess of 5 pounds of water at a feeding in addition to whatever quantity of condensed buttermilk it consumed. The amount of condensed buttermilk fed to a young calf at this age was usually a pound and a quarter a day, at the time the substitution for whole milk was complete. This was gradually increased until by the time the calf was three months old, it was receiving four pounds of condensed buttermilk a day, fed in two equal feedings. The condensed buttermilk was always fed diluted with warm water. Five pounds of water at a feeding gave the best results. A greater quantity than

this did not appear to give as good results as five pounds so that the quantity of water was kept constant, regardless of the quantity of condensed buttermilk dissolved in it.

In addition to the condensed buttermilk, the calves received alfalfa hay and a grain mixture composed of equal parts by weight of bran, ground oats, rolled barley, and linseed oil meal.

Skimmed Milk Powder for Calf Feeding: Three pure-bred Jersey calves were fed skimmed milk powder for a period of 80 days. The plan followed was approximately the same as that described in the feeding of condensed buttermilk. When the substitution for whole milk was completed, the calves received one pound of the skimmed milk powder diluted with nine pounds of water, and divided into two feeds per day.

The quantity of skimmed milk fed was later raised to two pounds a day diluted with nine pounds of water. In other words, the calf received about five pounds of the mixture at a feed, regardless of the amount of skimmed milk powder contained in the mixture.

These calves made an average daily gain of about one pound for the period of 80 days. This is considered only a fair rate of gain for Jersey calves of that age.

The Effect of Exercise and Feed Upon the Vitality and Breeding Ability of Bulls:

This is a continuation of the work reported in the 30th Annual Report. The plan of the work, together with the results to date, may be summarized as follows.

Period	I	II	III	IV	V
Feed	No Silage	Silage	Silage	No Silage	No Silage
Exercise	Exercise	Exercise	No Exercise	No Exercise	Exercise
No. Samples of Semen	12	5	5	4	3
Percentage Spermatozoen Alive	90	87	50	40	95
Hrs. of Fwd. Movement of Spermatozen	21	28	16	4	20

Note: In period V two samples were taken which showed no life whatever and these were excluded from the averages.

Official Testing:

The semi-official work has increased 16.2% over the year July, 1919, to July 1, 1920.

The increase in seven-day tests has been 29.1%.

The increase in retests has been 29.7%.

During the year ending November 1, 1921, an average of 65 herds were tested semi-officially each month. During the same time there was an average of 342 cows per month tested. This is an average of over five cows per herd.

The Jersey breeders with 30 herds containing 154 cows led in the number of herds tested per month and were second in number of cows. The Holstein breeders led in number of cows tested with a monthly average of 174 in 22 herds. The Guernsey breed was represented with 10 herds and an average total of 34 cows per month. Two Ayshire herds with an average of 12 cows per month were tested throughout this period. In June one Shorthorn herd started testing and had four or five cows on test each month since that time.

An average of 11½ supervisors were used during this period. They also conducted the Official Testing.

Number of 30-day reports for the year.....	10
Number of 7-day reports for the year.....	417
Number of verifications for the year.....	9
Number of retests for the year.....	100
Number of check tests.....	7

Needs of the Division of Dairy Husbandry:

More help is needed on the staff of the Dairy Division, both in the college and station. Only a very limited time on the part of the head of the Division is now available for investigational work and the details of such work must be handled by advanced students. This should be remedied as soon as there are funds for additions to the staff.

DIVISION OF ENTOMOLOGY AND ZOOLOGY

A. L. Melander in Charge

The Codling Moth:

Two problems relative to codling moth treatment confront the fruit grower, namely, the relative importance of the spray rod and the spray gun and the value of spreaders. To secure some information on these mooted points an extensive series of experiments was conducted near Spokane. An old Ben Davis orchard was divided into plots and corresponding trees were sprayed through the season either with the rod and clipper nozzle or with the spray gun. In each series part of the trees received the insecticide without spreader added, while part was sprayed with a soap spreader included. Incidentally, different strengths of spray, different proprietary brands of arsenate of lead, and two of the newer sprays, calcium arsenate and magnesium arsenate, were tried out. At harvest time results were tabulated by determining both the per cent of worm-free fruit as usual, and the coefficient number representing the ratio of worms to stings. Over 70,000 apples were examined when checking results.

Calcium arsenate was inferior to arsenate of lead in controlling the codling moth, and magnesium arsenate was still less efficient. Somewhat better results were obtained with the rod and clipper nozzles than with the spray gun, the ratio being an increased protection over the unsprayed trees amounting to 7.5 times for the rod and 5.7 times for the gun. The spray gun is easier to use and hence has won its favor, but it is clear that the clipper type of nozzle attached at an angle at the end of a long pole can place the spray to better advantage than is possible with the gun. However, for comparative purposes the clipper nozzles should be reamed out to permit the passage of the same quantity of spray as with the gun. Operators have perhaps been deluded by the loud hissing of the gun and the nearness of the emerging fog-like spray into a belief that it is

more efficient than the less visible driving fan spray. The extended experiments of this year again indicate that the contrary is true. This statement, however, is by no means a general condemnation of the spray gun. When the rod is conscientiously used it is capable of better returns, but the average operator will probably do more efficient work with the gun because of the greater ease in handling it. The gun can displace the rod with safety especially in orchards not excessively wormy. Under critical conditions the rod should be preferred.

With reference to the use of a spreader, ordinary laundry soap was added to the spray on half the trees, at the rate of six bars to the 200-gallon tank. Although there was a decided bettering of the spread of the spray over the fruit, and less blotching in drying, when soap was used, yet as heretofore, the improved spread was not followed by greatly increased control of codling larvae. Summing all the trees of the experiments, the use of the insecticide without spreader bettered conditions 6.9 times that of the unsprayed checks, while the addition of the soap raised this figure to 7.2. As far as codling moth control is concerned, the adoption of a soap spreader is optional. Other spreaders tried by this station have given less uniform spread of liquid over the waxy surface of the apple fruit than soap does, but are valuable in foliage sprays.

With respect to strength of application there was greater uniformity among the brands when used strong than when used weak. One brand of arsenate of lead gave three times as much protection when used at the rate of one pound to 50 gallons as when used at half that strength, while another brand showed little difference in effect between these two extremes.

San Jose Scale:

In continuation of an investigation in progress for several years at this station, San Jose scale was sprayed with identical solutions at Clarkston, Walla Walla, Yakima and Wenatchee in an endeavor to find out whether geographic

races of this insect, differing in susceptibility to spraying, occur. Incidentally some materials of local interest were used in part of the tests, so as to correlate them with the standard tests.

At the expiration of a month or so, the sprayed scales were individually examined under the binocular microscopes and by crushing them their condition as to whether living or dead was observed and recorded. On account of the heavy freezes of the year before, the sprayed branches were often encrusted with old dead scales which of course bore no reference to the experiments. Hence the 34,000 scales recorded represented only part of the insects actually removed from the bark.

The averages of the more interesting tests are tabulated below and show that the San Jose scale responds to the usual insecticides very differently in the several locations. The variation in susceptibility to sprays for this year is in accord with results obtained in previous years. The conclusion can be drawn from this experiment that actual strength of spray is not the only factor influencing its insecticidal value, that Clarkston and Walla Walla scales are more resistant than Wenatchee or Yakima scales, that dry polysulphids are not as efficient as the ordinary liquid lime sulphur, that oil sprays are more rapid in action than sulphid sprays, and that there is much variation in miscibility and efficiency among commercial oils.

Per Cent of San Jose Scale Alive After Treatment with Various Insecticides:

Material Used	Clarkston Interval 30 days	Walla Walla 44 days	Yakima 30 days	Wenatchee 28 days
Check, unsprayed	78	68	55	Not sent
Commercial lime-sul. 2 deg.	62	18	3	12
Commercial lime-sul. 3 deg.	14	34	9	2
Commercial lime-sul. 5 deg.	45	17	2	4
Dry lime-sul. 10/50	55	54	7	...
Dry lime-sul. 15/50	45	20	17	28
Dry lime-sul. 20/50	...	32	...	...
Dry soda-sul. 10/50	35	39	...	27
Dry soda-sul. 15/50	...	...	...	28
Dry barium-sul. 10/50	68	...	...	23
Dry barium-sul. 15/50	...	...	...	2
Dormoil, 5%	...	6	...	2
Dormoil, 6%	...	26	20	...
Spramulsion, 6%	1	...	20	...
Scalecide, 6%	10	...	...	...

Orchard Leaf Roller:

Spokane fruit growers have been unable to repeat the good results reported in other districts from spraying eggs of leaf rollers with oil sprays. In order to obtain reliable information on the action of locally used oils on this pest, branches heavily infested with egg masses were obtained during the winter and were sprayed and kept in the insectary until incubation of the embryos was completed. By this forced development advance information was obtained which served as a basis for spraying in the orchards at the end of the freezing period in early spring.

In order to obtain accurate counts the egg masses were examined under binocular microscopes and the condition of every egg was observed. Apparently the resistance of this pest to spraying is due in part at least to the protective action of the glairy egg covering. In both the insectary and the field experiments the spraying was overdone in order to be assured that every mass of eggs was thoroughly wet with the insecticide. Yet scarcely an egg mass could be found that later did not show some eggs hatched, the number at times amounting to virtually all the eggs of the cluster.

A brief summary of the data is here given in order to show how remarkably resistant the orchard leaf-roller is to standard sprays.

Material Used	—Per Cent of Eggs Hatched—	
	Insectary	Orchard
Dormoil, 12% .....	.....	20
Dormoil, 10%	6	62
Dormoil, 8%	51	68
Dormoil, 6%	4	.....
Dormoil, 5%	33	.....
Spramulsion, 12% .....	.....	91
Spramulsion, 10% .....	.....	89
Spramulsion, 8%	58	.....
Scalecide, 10% .....	.....	33
Scalecide, 8% .....	.....	66
Dormant soluble soil, 10% .....	.....	61
Dormant soluble soil, 8% .....	.....	73
Sulco, 6% .....	.....	76
Sulco, 5% .....	.....	81
Dormoil, 6% and soluble sulphur .....	.....	66
Dormoil, 8% on wet branches	23	.....
Dormoil, 8% and washed off	35	.....
Spramulsion, 8% on wet branches	57	.....
Spramulsion, 8% on washed off	31	.....
Checks	85	92

Wire Worm Investigations:

Wire worm investigations were continued by the representative of the Bureau of Entomology of the U. S. Department of Agriculture in the semi-arid section more particularly at Ritzville and in connection with the Adams Branch Station at Lind. Definite results have been secured in the life history studies and it is expected that after another season's work the principal points in the life history may be cleared up.

Needs of the Division of Entomology and Zoology:

Although the Division of Entomology and Zoology has three investigators on its staff, these men because of class work can not give to exceed fourteen months' time per year to Experiment Station work. With limited time and the necessity of concentrating attention on a few definitely approved projects, the output along practical lines falls short of public demand. More help is needed.

Specific investigations should be undertaken on the woolly aphis of the apple, orchard leaf-rollers, red spiders, strawberry root weevil, aphid control, budmoth; on nicotine substitutes, oil sprays and soil insecticides. Studies on the stem maggot of wheat, wire worms, cranberry insects, the destructive introduced earwig, the imported satin moth, and the root maggots of vegetables should also be made possible. The zoologist should be given means to investigate destructive rodents, particularly the field mice of the Yakima country.

DIVISION OF FARM CROPS

E. G. Schafer in Charge

Varietal and Cultural Experiments.

The growing of varieties of wheat, oats, barley, rye, flax and peas under uniform conditions in order to determine their comparative development and value was continued. The acre yield for 1920 and the average for a seven-year

period are given in pounds and bushels in the following table:

TABLE—ACRE YIELD OF LEADING VARIETIES OF FIELD CROPS ON THE COLLEGE FARM AT PULLMAN, WASHINGTON

Variety	Wash. No.	1920		7-yr. Av. 1914-1920	
		lbs.	bu.	lbs.	bu.
Hybrid 128—Winter	592	3120	52.0	2598	43.3
Bluestem—Spring	265	2328	38.8	2406	40.1
Turkey Red—Winter	328	3108	51.8	2334	38.9
Early Bart—Spring	618	2910	48.5	2136	35.6
Banner—Oats	764	3315	103.6	2838	88.7
White Winter—Barley	957	4378	91.2	2654	45.3
Beldi—Spring Barley	967	3706	77.2	3274	68.2
Yellow—Eye	995	2139	38.2	1585	28.3
Bangalia—Peas	556	2466	41.1	1830	30.5
Minn. No. 25—Flax	1085	510	9.1	661	11.8

a. Six-year average.

b. Five-year average.

The first two varieties of wheat are grown in regions which have more than 16 inches of rainfall, while the second two varieties predominate in those areas with less than that amount.

The experiment in which various combinations of wheat, oats, barley and peas were grown as mixtures was discontinued with the 1920 crop. More pounds of grain were obtained with wheat alone than with any combination of crops seeded together.

The experiment on date of seeding winter wheat and also the cultural experiments of Field VI are being continued. Twenty years' results from the cultural experiment on this field were published in Bulletin No. 160 of this station.

Crop Improvement Investigations.

A special study of bunt (*Tilletia tritici*) resistance in wheat, resistance to covered smut (*Ustilago levis*) in oats, and covered smut (*Ustilago hordei*) in barley was made in the search for suitable material for hybridizing. More than 1200 strains were tested for resistance, and at the same time this material was studied for other characters of interest.

The work in inheritance of bunt resistance conducted during the year includes the third generation of two crosses, Forty Fold X Turkey and Forty Fold X Red

Russian, as well as selections of other crosses in the fourth and fifth generations. The results of the smut work in wheat since 1914 were summarized and submitted to the Journal of Agricultural Research for publication.

Spring habit, glume and grain color, pubescence of chaff, and awnlessness in wheat are being investigated in respect to their genetic relationships.

Species hybrids are being made in connection with sterility studies conducted in co-operation with the Maine Agricultural Experiment Station.

Forage Investigations:

The forage nursery of alfalfa, clover, peas, beans, sunflowers and grasses has been enlarged to include a number of varieties of grasses from the United States Department of Agriculture. The main object of the work is to determine the comparative values of forage crops and the methods necessary to obtain maximum production.

The experiments with sunflowers have been expanded to determine the distance apart that they should be grown for seed and silage.

Crop Rotations:

This experiment to determine the effects of various crops upon the growth of the succeeding crops, and to work out a cropping system for permanent agriculture in the Palouse country is being continued.

Distribution of Seed and Bacteria Culture:

Twenty-five tons of pure seed were distributed to 150 farmers in 23 counties of Washington. In co-operation with the Division of Bacteriology, bacteria culture was sent to 1031 parties and went to every county in the state.

DIVISION OF FARM MANAGEMENT

Geo. Severance in Charge

The Cost of Milk Production and Dairy Farm Organization:

The Division of Farm Management has continued work

on "The Cost of Milk Production." Usable records were secured from 91 dairy farms in Whatcom, Snohomish, Pacific and Wahkiakum Counties in the fall of 1920 and the results tabulated.

One thousand five hundred and two cows produced 10,148,-381 pounds of milk at an average cost of \$2.88 per 100 pounds delivered at the local plant or shipping point. The costs on different farms ranged between \$1.94 and \$4.39 per 100 pounds. It was found that 52.7% was produced at costs ranging between \$2.53 and \$2.92 per 100 lbs. Feed constituted 48.31% and man labor 24.2% of the total cost. From the data secured, the production of 100 pounds of milk was found to require the following quantities of the measurable factors of production: 18.78 pounds of grain, 43.13 pounds of hay, 49.5 pounds of silage, 5.6 pounds of roots or kale, .093 months of pasture and 2.19 hours of man labor. If local prices are applied to these quantities and the sum multiplied by 1.378, it is believed that the result will approximate the average cost of production. A mimeographed summary was sent to the co-operators. The survey is being repeated after which the two years' records will be summarized and published.

Studies on Cost of Wheat Production and Grain Farm Organization in the Palouse:

Studies on the Cost of Wheat Production and Grain Farm Organization in the Palouse conducted in co-operation with the Office of Farm Management of the United States Department of Agriculture and the University of Idaho were continued. The 229 usable records gathered and partially tabulated in the summer of 1920 by the co-operating parties were completed by the Office of Farm Management and a multigraphed report issued to the co-operating farmers. The survey was repeated during the summer of 1921 and the Office of Farm Management is tabulating the data. The survey will be repeated in the summer of 1922, after which results will be published.

The first preliminary report of this study shows that the

average cost of producing winter wheat in 1919 was \$1.63 per bushel on owned farms and \$1.40 on tenant farms, and of spring wheat \$1.83 per bushel on owned farms and \$1.54 on tenant farms, the cost of winter wheat on different farms ranging from \$0.70 to \$4.00 per bushel and spring wheat from \$0.80 to \$4.00 per bushel. Of all winter wheat included in the study, 86% was produced for \$1.90 or less per bushel. Eleven and eight-tenths per cent cost over \$2.00 per bushel, while 4.2% cost over \$2.50 per bushel. Eighty-five and four-tenths per cent of spring wheat was produced for \$2.20 or less per bushel while 4.8% cost over \$2.50 per bushel.

The preliminary report shows the following basic acre requirements for producing wheat:

	Winter Wheat on fallow	Winter Wheat on pea ground	Winter Wheat after other crops	Spring Wheat
Direct man labor, hours.....	8.0	8.4	6.00	7.00
Horse labor, hours.....	33.7	22.4	22.9	29.8
Seed, bu.	1.4	1.4	1.3	1.3
Twine, lbs.	2.9	3.5	21.0	2.0
Per cent of total cost represented by direct labor.....	21.3	21.4	26.8	27.1

The study indicates a material reduction in the cost of producing wheat where peas are grown on the summer fallow and also where heavier yields are secured through good farming methods.

On farms operated by owners, the average investment was \$45,978, labor income \$1766 and value of living secured from the farm \$688. On tenant farms the tenants' average investment was \$4596, labor income \$2420 and value of living secured from the farm \$558. Owners of rented farms secured an average return of 4.9% on their investment.

This Division co-operated with the Office of Farm Management in securing general farm survey records from over 250 logged-off land farms in Western Washington during August, September and October, 1921. The data is being tabulated by the Office of Farm Management.

A two-year cost of milk production study will be made in Spokane County beginning with the fiscal year 1921-22

to supplement the Western Washington study on account of the marked contrast in climatic conditions.

The Cost of Production and Farm Organization Studies should be extended to include the principal types of farming and the major crops and livestock enterprises of the entire state. That such a program may be followed there should be funds for at least one full-time investigator on the Experiment Station Staff and one clerk.

DIVISION OF HORTICULTURE

O. M. Morris in Charge

Five projects were given attention during the year. The project "Orchard Pollination" was formally reported on in Experiment Station Bulletin No. 163. The work in this field has not been completed, but enough has been done to answer many of the pressing questions of importance to the apple growers of the state. This report shows that nearly all of the common varieties of apples grown in the state are partially or entirely self-sterile. The blossoming dates of the more common varieties are given and can be used as a basis for the selection of the inter-pollinating varieties. Work on the June Drop and its causes also was reported. It was shown that lack of complete fertilization of the blossoms is a contributing factor in June Drop. Further work on this project will be done as soon as opportunity permits.

Apple Rosette:

Apple rosette is fast disappearing from the commercial orchards of Washington. This is especially true of orchards that have been planted to leguminous cover crops. Some of the older orchards which have not received cover crop treatment still show some evidence of the disease but usually less than five years ago. The continuous irrigation, use of fertilizers and pruning, have undoubtedly been factors in eliminating the trouble. In the cover cropped orchards the trouble is sometimes found on a few twigs in the apple

tree but seldom to a destructive degree. So completely has the soil improvement practice of fruit growing districts overcome this difficulty that it has at present dropped distinctly into the background and is not now receiving any considerable amount of attention from the fruit growers.

Orchard Cover Crops:

Investigational work in orchard cover crops has been carried into three of the principal fruit growing districts of the state: the Spokane Valley, Chelan County and the Yakima Valley. Fertilizer plots in the orchards of the Spokane Valley indicated that none of the common fertilizers used were of any particular value to these orchards. The indications were that conditions other than lack of plant food materials were of primary influence in retarding the development of the orchards.

The combination of cover crops and nitrogen-bearing fertilizers gave indications of improvement in tree growth and fruit production.

Hairy or winter vetch, field peas, red clover and alfalfa have been used successfully as cover crops in the valley. Very gratifying results have been obtained with the use of vetch, field peas and clover. The work with alfalfa has not yet furnished a basis for a positive statement as to its value in the Spokane Valley. The results indicate that the cover crop should remain on the ground during the entire summer season. Much remains to be done before positive statements can be made relative to the best methods of handling these crops in the type of soil existing in this section.

In the Wenatchee and Yakima districts nitrogen-bearing fertilizers are the only fertilizers that have consistently given improvement in tree growth or crop production. Some soils have not responded to them or any other form of fertilizer when added in concentrated form. The physical condition of soil appears to be more definitely the limiting factor of its possible crop production than is the plant food

content. In these sections alfalfa has gained most favor as a cover crop. Some few orchardists have had good results with clover and some with hairy vetch. It seems clear, however, that the vetch and clover are much more limited in their adaptability to cover crop uses in these districts than alfalfa.

Methods of cover crop handling vary so greatly in their tendency to maintain a good crop or to destroy it that there is great need for careful study and investigation of the possible lines of practice.

Fruit Storage.

The fruit storage work to bring to light the influences existing during the growing season that are most prominent in modifying the keeping qualities of the fruit produced have been continued. This has proceeded far enough to indicate that there is a great deal of misunderstanding as to when a fruit is mature or ready to harvest for storage purposes. Fruit permitted to remain on the trees purely for the purpose of obtaining a high color, lost keeping quality when compared to that gathered earlier. The data at hand indicate that the degree of maturity attained and the temperature to which the fruit has been exposed during the last few days or weeks prior to harvest, may combine to exert a great influence over its keeping quality. The data on the temperature through which the fruit has grown to maturity give such conflicting results in the storage life of the fruit that it is evident that there are other factors of very great importance involved in the problem.

Seed Potato Production:

Work in seed potato production has now been carried on through the second summer. Five varieties are being used. Several strains of each variety have been obtained and planted on the Experiment Station grounds. In the summer of 1920 there were 22 different strains of Netted Gem, four of Rural New Yorker, eight of Earliest of All,

seven of Burbank, three of American Wonder, and three of Gold Coin. In the work for 1921 the Gold Coin was dropped from the list. In securing these lots an attempt was made to get seed from the best crops available. The variation in the productivity of the different lots is indicated in the Netted Gem. The plot number and yields in pounds per acre were as follows:

		Lbs. per Acre			Lbs. per Acre
Plot 1	.....	11,698	Plot 12	.....	9,738
Plot 2	.....	3,764	Plot 13	.....	8,120
Plot 3	.....	8,463	Plot 14	.....	10,018
Plot 4	.....	10,885	Plot 15	.....	8,992
Plot 5	.....	9,238	Plot 16	.....	11,421
Plot 6	.....	9,331	Plot 17	.....	11,356
Plot 7	.....	6,814	Plot 18	.....	10,594
Plot 8	.....	11,138	Plot 19	.....	11,001
Plot 9	.....	11,730	Plot 20	.....	12,323
Plot 10	.....	11,045	Plot 21	.....	12,963
Plot 11	.....	10,003	Plot 22	.....	13,952

This material was collected from widely different sources. Part of it came from Southwest Washington, Western Oregon, Central Washington, Eastern Washington and Idaho. A few of the plots were from material grown on the Experiment Station at Pullman in 1919. The yield of these plots relative to each other ranked approximately the same as in the summer of 1919. The work has not been conducted long enough to form a basis for stating that any one locality produces seed potato material of superior quality. The indications are, however, that superior producing material in one locality will also show that same characteristic when planted in another district in different soil and climatic environments.

Needs of the Division:

Because of the large acreage devoted to fruit and the heavy investment in fruit production, it is extremely important that opportunity in time and funds be given for investigating the many problems that confront the fruit grower today and are likely to be encountered in the future.

The heavy loss sustained each year as a result of winter injury to the root system of trees is sufficient cause for

alarm. Exhaustive investigation should be made of the possibilities of obtaining a more hardy stock and of developing methods of orchard management that would reduce such loss to a minimum.

Investigations should be made to determine the methods of pruning and orchard management which will contribute most to regularity of crop production and improvement of grade or size of fruit. The small apple is a serious handicap to the fruit growers and it does not seem probable that the regularity of crop production and the size of the fruit can be controlled entirely by common systems of pruning and soil management.

Investigational work to assist the peach growers in carrying their trees through the winter and late spring in such condition as to avoid as far as possible the danger of late spring frosts should be continued. The peach crop is so frequently destroyed by late spring frosts that the growers suffer severely in crop production and the consumer in the price of the fruit.

Grape growing is a developing industry in the state. Studies of varieties, methods of propagation, tillage methods and systems of pruning and training, are all of importance and should be given attention by the Experiment Station.

Interest in nut growing is increasing. To determine the adaptability of varieties, the degree to which they are self-sterile or self-fertile, and the adaptability of the district and systems of orchard management by means of commercial plantings is an expensive operation for the individual. Investigational work would be of much value along these lines.

Vegetable seed production in the United States has become a matter of very considerable importance since the World War. The climate and soil of Washington have given promise of conditions favorable to the development of that industry. Careful investigation of methods and practices involved are needed.

Methods of management of cranberry bogs is of vital importance to those engaged in this industry. The cranberries in the northwest are produced under methods entirely different from those in the older cranberry sections. Just what methods should be followed is still an open question to be decided only through careful investigations.

DIVISION OF PLANT PATHOLOGY

F. D. Heald in Charge

Wheat Smut:

The study of the relation of spore load of individual grains to the per cent of smut in the crop was continued. Samples of spring wheat showing different varieties and varying quantities of smut were obtained direct from farms or warehouses. Spore counts showed 0 to 20,176 spores per grain. The maximum per cent of smut was 20, while a considerable number of plantings remained smut-free, even though the spore counts showed considerable smut. The results showed that considerable of the smut on the seed must have lost its infective power. Numerous samples showing 100-500 spores per grain remained smut-free. The experiments again point to the conclusion that such resistant varieties as Marquis, when seeded in the spring will rarely have sufficient smut to justify the expense of seed disinfection.

A more extensive test was made of the relation of the spore load to the per cent of smut appearing in the crop, using six spring varieties, with artificial smutting varying from 0.005 grams to 3 grams of powdered smut per 100 grains of seed. Twelve different degrees of smutting, varying from a few hundred spores per grain to a maximum of 278,000 were used for each sample. The per cent of smut obtained in the crop was generally higher than in similar degrees of smutting of farm infected samples. These studies have made it possible to predict by microscopic analyses the per cent of smut which will appear in spring

seedings, when seed disinfection is omitted, and will indicate when the omission is practical.

The promising results obtained with the 1/1 bluestone treatment in preventing smut from naturally contaminated summer fallow led to special tests to the effect of this treatment on the per cent of germination. Six varieties were used: Early Bart, Bluestem, Hybrid 143, Little Club, Jenkins Club and Marquis. The per cents of germination of the 1/1 bluestone-treated seed ranged from 46.5 to 76.5. Presoaking did not seem to be of any value in this method in reducing seed injury.

The following seed treatments were tested on two varieties of spring wheat that had been heavily smutted: Hypoform, chlorophol, copper carbonate dust, anhydrous copper sulphate dust, bluestone 1/1 sprinkle, sulphur and formaldehyde. Perfect control was secured by the following:

1. Hypoform	1 lb. to 5 gals. water	30 minutes
2. Chlorophol	1 part to 300 water	60 minutes
3. Copper carbonate dust.....	2 ozs. per bushel	
4. Copper sulphate, anhydrous one part, calcium carbonate, one part.....	2 ozs. per bushel	
5. Sulphur	20 lbs. per bushel	

Seed treated with formaldehyde 1 lb. to 40 gallons water and the bluestone 1/1 sprinkle gave traces of smut. There was practically no reduction in germination in the case of hypoform, chlorophol, copper carbonate dust and anhydrous copper sulphate treatments.

Field tests secured by the Extension Plant Pathologist point to the probable value of the copper carbonate dust treatment in reducing the smut from soil contamination. Present information will justify the conclusion that the copper dust treatments are as effective as either formaldehyde or the bluestone steeps, more convenient to use and less injurious to the seed.

The Foot Rot of Wheat:

The increasing severity of the foot-rot of wheat, a trouble first reported in this state in 1918, has led to the establishment of a co-operative project with the Cereal Office of the

U. S. Department of Agriculture. The past seasons work included field surveys to obtain data on severity, distribution and the possible relations of climatic factors and cultural practices to occurrence of the disease.

The foot-rot was found in severe form in at least 40 per cent of the 4000 acres of winter wheat in the Spokane Valley, and traces were found in a number of outlying districts. Many fields were so severely affected as to necessitate cutting for hay, and others which were allowed to mature showed 30 to 50 per cent reduction in yield. No definite relation of soil, time of seeding or variety to the occurrence of the disease was established. Jones' Winter Fife and Gold Coin or Forty Fold were the varieties most generally grown in the affected regions.

A fungus has been found in constant association with the characteristic basal lesions. Repeated isolations have been made but all of the cultures have remained sterile, and no sporulating form has been connected with the disease in the field.

Field experiments have been started in the Liberty Lake section to test the effect of fertilizers, periodic seeding, the comparative resistance of varieties, the effect of physical characters of the soil and the possible relation of biologic factors.

Rhizoctonia Diseases:

The work on this project was confined to the study of the western blight or yellows of the tomato. Diseased plants were secured from the vicinity of Pullman and Clarkston, Washington and Lewiston, Idaho. A laboratory study was made of these plants and isolation cultures were made from the root system of each plant. Thirty diseased plants in all were studied in this way. The mycelium of *Rhizoctonia* in greater or less abundance was easily found on the root systems of 26 plants, none of this fungus being found on the other four plants. Typical *Rhizoctonia* was obtained in pure culture from but two plants. From 26

plants two species of *Fusarium* were secured in pure culture. No isolations were secured from three plants because of contaminated culture.

Failure to secure cultures of *Rhizoctonia* from each plant showing the fungus by macroscopic or microscopic examination was without doubt due to the difficulty of separating this sterile mycelium from sporulating species. The results of the isolations together with the microscopic examinations show that both *Rhizoctonia* and *Fusarium* are present on the root systems of diseased plants and suggest their combined action in producing the blight. From these plants, two from Pullman and one from Clarkston, the cultures of *Fusarium* did not prove to be pure cultures. The fruiting stage of a *Melanospora* appeared in these cultures when they were two or three weeks old. The *Fusarium* produces a condition of the culture medium necessary before the fruiting stage of the *Melanospora* will develop. In a like manner it is entirely possible that the *Fusarium* developing with the *Rhizoctonia* produces substances or a condition which is necessary before the *Rhizoctonia* fungus can cause the disease under investigation. Work is in progress to determine if such a relation does exist between these two fungi. The study is expected to throw some light on or make possible an explanation of the baffling results secured in former years by artificial inoculation in the field.*

The Plant Disease Survey:

This work has been continued as in former years with the co-operation of the Plant Disease Survey Office of the U. S. Department of Agriculture. This co-operation made possible summer survey trips by the staff. The foot-rot disease of wheat was present in epidemic form in Spokane County and also occurred with less severity in Klickitat County. A detailed survey in Spokane County was carried out during the past summer to determine definitely the

*Heald, F. D. and Venus W. Pool. The influence of the chemical stimulation upon the production of perithecia by *Melanospora pampeana* Ann. Rep. Neb. Agr. Exp. Sta. 22. 130-132 1909.

extent of the trouble and experimental work undertaken as reported elsewhere.

The apple industry in the White Salmon Valley was found to be seriously menaced by the anthracnose disease. A considerable acreage of the Spitzenburg variety has been rendered unprofitable and will eventually have to be removed because of this trouble.

Head smut of corn has been reported during the past season from Central Washington. This is a new locality for this disease which is capable of attacking sorghum also. Cane gall on blackberry and raspberry occurred in severe form in Western Washington. Snapdragon rust was reported as severe from new localities. The Sclerotinia wilt of sunflower was reported as destructive on artichoke as well as sunflowers in Western Washington. An interesting case was reported from the Walla Walla section of silvering of the foliage on the prune due to injury from the low temperatures during the fall of 1919.

The following new diseases have been reported: Head smut of proso or hog millet (*Ustilago panici* milacei). nematode disease on carrot and strawberry, root knot of strawberry, and the *Rhizoctonia* disease of watermelon.

The expected has happened and that dread disease of the pine, the blister rust, has been reported to be widely distributed on black currants in Southern British Columbia and has been reported as far south as Mt. Vernon, Washington. This now stands as a present menace to the extensive forests of the five-needle pines on the Pacific Coast.

During the year, 660 specimens, accompanied by inquiries, were received for diagnosis. It is interesting to note that in the last seven years, the Department of Plant Pathology diagnosed 735 different diseases on 165 different economic hosts.

Some Needs of the Division of Plant Pathology:

In order that the Division may more effectively serve the state, the especially pressing needs are as follows:

1. Increased funds for the publication of work already completed.

2. Additional man power for the prosecution of investigations already in progress, and also for new work that should be undertaken.

3. The provision of adequate greenhouse facilities to make possible especially the growing of experimental plants under controlled temperatures.

4. More funds for operating expenses. Present resources make impossible the carrying out of research problems at points distant from the Experiment Station.

5. Increased library facilities by the addition of much needed reference books and sets of standard periodicals.

Some of the more important disease problems that need special investigation are as follows:

1. The collar or crown rot of fruit trees, especially apples.

2. The California blight of cherry, peach, apricot and plum; etiological and control studies.

3. The control of apple tree anthracnose with special studies of dissemination.

4. Dusting vs. spraying for the control of fruit diseases.

5. Laboratory and field studies of the efficiency of commercial fungicides with special reference to control of fruit diseases.

6. The fungous diseases of the cranberry and their control.

7. The etiology and control of cane gall of blackberry.

8. Bacterial blight of the raspberry. Study of the morphology and pathogenicity of the causal organism, and the etiology of the disease.

9. The degeneration diseases of the potato, with special reference to seed production.

10. Market and transportation diseases of lettuce.

11. Market and transportation diseases of onions with special reference to neck rot and slimy soft rot.

12. Market and transportation diseases of the potato.

DIVISION OF SOILS

F. J. Sievers in Charge

Soil Nitrate Studies:

Confirmatory of previous results from tillage work which showed available nitrogen as the limiting factor of soil fertility on soils and under climatic conditions represented at the Experiment Station at Pullman, nitrate of soda and ammonium sulphate fertilizers produced marked increases in the yield of wheat after every application for three successive years. Best yields were obtained from spring applications of fertilizers on winter wheat. This further emphasizes the fact that not only the amount of available nitrogen in the soil but also the proper distribution is important.

Nitrogen fertilizers when applied with straw were effective in overcoming the decreases in yields of small grain so commonly experienced when these are grown after straw has been applied alone. Indications are that these fertilizers have the same effect on the decomposition of straw and produce the same results as the high nitrogen content of virgin soils when straw is returned to them.

Continued work on the effect of soil nitrates on plant development showed that under field conditions where nitrates were not limited the lightest seeding of winter wheat produced the greatest amount of tillering. Tillering, however, was not strictly inversely proportional to the rate of seeding, but the heaviest seeding produced the greatest number of culms per unit area. The number of culms per acre can therefore be controlled in part by regulating the rate of seeding, a matter of practical importance from the standpoint of its effect on lodging and "burning." The rate of seeding also had a direct bearing on the size of the spikes produced to the extent that all rates within the limits of this experiment produced practically the same yield.

Work on the effect of soil nitrates on the yield and quality of wheat was continued on the Adams Branch

Station at Lind. Soil moisture in this region has been the limiting factor in crop production to such a pronounced degree during the last three years, due to an abnormally low rainfall, that variations of soil nitrate content had very little if any influence.

Crop Rotations:

Where either vetch or peas were used as a green manuring crop the following crop of wheat produced not only as high a yield as good summer fallow, but the wheat was of as high quality. From an economic standpoint, as far as immediate production is concerned, green manuring can not be recommended.

Peas were used very successfully as a nurse crop for both red and sweet clover even under conditions where the peas were harvested for seed and produced 30.3 to 25.7 bushels per acre respectively. This is under conditions where small grain nurse crops were failures.

Where phosphorus and potassium fertilizers and lime were used separately and in combination on alfalfa, no increase or variations in yield were obtained.

Where gypsum was used on alfalfa in the spring, an increase in yield of 33% was obtained the same season. Other results from the use of gypsum indicate that the greatest increases are not obtained the first year and consequently the initial application should be made earlier.

Gypsum produced no increase when applied to small grain but when used on legumes (alfalfa and red clover) it not only increased the yield but produced a hay of higher nitrogen content. This would indicate that gypsum here acts as a stimulant and not as a plant food.

Organic Matter Studies:

Continued work on the return of straw and crop residues to soil shows that the nitrogen-carbon ratio in the materials returned has a very pronounced influence on the kind and rate of decomposition. Organic materials like straw, having a wide carbon-nitrogen ratio (1 to 75), when applied to

the soil will produce a depressing effect on the nitrate development and such effect will be felt until there has been sufficient decomposition to cause this ratio to approach that of the organic matter in the soil (1 to 13). Before this stage of decomposition is reached nearly all of the carbon is lost as carbon dioxide and consequently residues like straw cannot be depended upon materially to influence the soil organic matter.

Where organic matter having a narrow nitrogen-carbon ratio (1 to 10) like legume hay, legume green manure or legume sod is incorporated into the soil, there is an immediate and rapid nitrate development. There is also less loss of carbon dioxide and indication of greater organic matter maintenance. The resulting high nitrate content of the soil following the plowing of a legume sod frequently causes lodging or "burning" of the succeeding grain crop. When straw is spread on such sod before plowing, this difficulty can be largely overcome in that such application regulates the rate and kind of decomposition and thus controls the nitrate development. This practice provides for the practicable utilization of straw for the maintenance of organic matter and at the same time distributes the beneficial effects of the legume crops over a greater number of years.

Soil Surveys:

To aid in the land settlement program this division co-operated with the State Department of Conservation and Development by making several soil surveys and reports covering the projects under consideration as follows:

- 6000 acres near Sequim in Clallam County.

- 4000 acres near Forks in Clallam County.

- 4000 acres near Ethel in Lewis County.

- 900 acres near Twisp in Okanogan County.

- 1000 acres near Newport in Pend Oreille County.

Miscellaneous Work.

About 700 samples of soil sent in by farmers were tested and reports were made concerning their fertility, 18

samples of marl and limestone were analyzed and 108 samples of soil were tested for alkali. Several soil surveys of small tracts were made for private concerns.

Needs:

The plan adopted by this Division of solving all soil management problems as they relate to the several distinct agricultural areas into which this state is naturally divided by soil and climatic conditions needs greater financial support before the desired service can be given.

A systematic program of agricultural development in the State of Washington is at present limited by the lack of definite information concerning specific soil types and conditions and this information can be obtained only through a detailed soil survey. Results from such a survey are essential in planning and applying investigational work for lands already under cultivation in order that they may be made more productive and in determining agricultural suitability of lands at present undeveloped in order that unjustifiable reclamation expenditures may be avoided.

The cost of such a survey is so slight as compared to its value to any land development program that the first step in land settlement for any given section should be a survey of the soil types of that area.

DIVISION OF VETERINARY SCIENCE

J. W. Kalkus in Charge

Goitre and Associated Conditions in Domestic Animals:

All active work in connection with investigation of this problem was discontinued during the past year. General Bulletin No. 156 entitled "A Study of Goitre and Associated Conditions in Domestic Animals," was published in July, 1920. This publication deals in detail with a description of the disease together with results of experimental work conducted at this station, 1915 to 1920 inclusive. The bulletin is profusely illustrated with original photographs

of clinical cases occurring in various species of animals and microscopic sections of thyroid glands.

Orchard Horse Disease:

From the experiments thus far conducted in the investigation of this disease, evidence seems to indicate that in all probability lead arsenate, which is present on orchard hay, is responsible for this condition in horses. The feeding of orchard hay on farms has been largely discontinued and because of this there has been a material lessening of the number of cases of this disease.

Red-Water (Cystic Haematuria) in Cattle:

During the summer of 1920, the Station Veterinarian started a series of co-operative experiments with farmers in a number of counties west of the Cascade Mountains where this disease is prevalent in an effort to determine the value of certain agents in the treatment of red-water cows by irrigation of the bladder. The results of this work were unsatisfactory chiefly because of the fact that stockmen who undertook to treat their cows did not continue the work long enough to warrant any conclusions being drawn. The results of this work were so variable that they do not warrant publication.

THE ADAMS BRANCH EXPERIMENT STATION

M. A. McCall in Charge

The period, 1917 to 1921 inclusive, during which experimental work has been in progress on the Adams Branch Experiment Station has been unusually dry and unfavorable from the standpoint of crop production. The average annual rainfall from September 1st, 1916, to August 31st, 1921, which covers the amount available for crop use during this period, was 7.01 inches. This low average, when compared with an average of 11.87 inches for the same locality for the period from September 1st, 1897, to August 31st, 1906, emphasizes the severity of conditions and eliminates any necessity of explaining low yields. On the other hand

these severe conditions have made the period from an experimental standpoint a very favorable one, and because the factors responsible for crop reaction have been very clearly defined and the reaction of crops to differences in method or treatment has not been masked by other factors, it has been possible to determine certain principles involved in moisture conservation which have not heretofore been recognized.

The investigational work on the Adams Branch Experiment Station is chiefly concerned with cereals and cereal production and consists largely of varietal and cultural experiments with those cereals best suited to the district, and with soil studies concerned with the problems of dry farming.

Because of the continuous moisture shortage, yields have been low. For the entire five-year period the varietal experiments with various crops have resulted in the following as leaders:

Winter Wheat—Turkey Red (Wash. 326).....	10.5 bu.
Spring Wheat—Early Baart (Wash. 618).....	11.3 bu.
Winter Rye—Yellow Von Rumker (Wash. 995).....	9.8 bu.
Spring Rye—Mexican (Wash. 992).....	8.9 bu.
Spring Barley—California (Wash. 959).....	13.9 bu.
Spring Oats—Kherson (Wash. 1049).....	15.1 bu.
Field Peas—Kaiser (Wash. 554).....	7.6 bu.

Cultural experiments with winter wheat have shown no consistent advantages from harrowing the crop in the spring, and while in some instances the harrowed crop has equaled the unharrowed crop, it has not been superior and in many instances has been less.

The most important experiments conducted on the station, and those giving the most valuable results, are those concerned with soil moisture and summer-fallow tillage. Results have been secured from these experiments which are fundamental in their application and which are therefore of special value. Briefly the summarized data from these experiments show that:

1. During a period of scanty precipitation the conservation of moisture is most concerned with getting a natural supply into the soil.

2. Contrary to former opinion, a loose surface condition

of the soil during the period of absorption is not favorable to moisture absorption for the type of climate and soil found in this district.

3. A loose soil condition during the fall is particularly detrimental in saving moisture for crop use, and dry-fall tillage especially should be avoided.

4. When a loose soil is detrimental in effect on moisture conservation, the degree of this unfavorable effect is directly proportional to the depth of the loose soil.

5. The more dry the average conditions at the time of tillage, as plowing, for instance, the more shallow should be the depth of tillage.

6. The moisture content of the surface soil at the time of tillage influences the settling of the stirred soil and its consequent degree of looseness. With a higher moisture content the greater the settling and the deeper the tillage may be. This should be considered in deciding on depth for tillage.

7. Early spring gives the necessary combination of conditions when tillage is most effective in promoting both moisture absorption and its retention.

Studies on the quality of wheat grown on the various plats of the summer fallow tillage experiments indicate that the nitrate-nitrogen of the soil after the year of fallow has a very important bearing on crop quality, especially when the crop is fall sown, and to a less degree if the crop is spring sown.

WATERVILLE BRANCH EXPERIMENT STATION

C. E. Hill in Charge

The Waterville Branch Experiment Station is located near Waterville in Douglas County, Washington. It is operated under a co-operative agreement with the Office of Forage Crop Investigations, United States Department of Agriculture.

The regions served by this station are the wheat producing area of North Central Washington and similar

areas having an annual precipitation of about 12 inches, coming mostly during the winter months.

The work conducted includes the investigation of different phases of the production of adapted crops that may be grown for forage and their relation to crops that are grown for other purposes. Particular attention is being given to experiments to determine the best crops and methods of production that will provide, at the lowest cost, feed for the work stock necessary to carry on the farm operations in the production of wheat; and also feed for other farm animals that may be raised to supply the farm needs and the local or any outside demand for animal products. In this connection, an effort is being made to reduce to a minimum the cost of maintaining the necessary stock on the station and to determine for average conditions the number of acres required to produce this feed per animal unit.

An important problem to be solved by this station is that of determining the most economical method of providing pasture for stock on farms having little or no natural pasture. The usual practice is to delay the time of plowing on land that is to be summerfallowed and to pasture the stock on the growth of volunteer wheat. Experiments have been started to determine the value of this pasture when charged to the reduction in the yield of the following crop of wheat; and to see if cheaper and better pasture can be provided by sowing a sufficient area to small grains.

For the production of hay, silage and grain, the best results have been obtained with winter wheat. In growing winter wheat, the importance of clean tillage methods and of seeding at the proper time, rate and depth, is indicated by the results which have been obtained.

The best yields of hay, silage and seed have been obtained from wheat that came up between the last day of August and the last of September. In 1921, the average yield of wheat that came up on August 25 was 8623 pounds of air dry hay and 57.6 bushels of seed per acre. A stand of wheat could be obtained at this time only on ground given

clean tillage. On ground given ordinary poor tillage, a stand could not be obtained until after a rain and the grain did not come up until October 8. Wheat sown on this ground yielded 3407 to 4733 pounds of hay and 29.8 to 38.0 bushels of seed per acre—the yields varying with the time of plowing and tillage before plowing.

In seeding at different times and under different conditions, the yields have not been reduced by increasing the rate up to 105 pounds per acre, but the yields have been reduced when the amount sown was not sufficient to give a thick enough stand for the crop to adjust itself by stooling. One bushel of seed per acre has given satisfactory results when seeding has been done medium early and under conditions favorable for germination. For late seeding or under conditions unfavorable for germination, higher rates have given better results.

Kanred winter wheat, a variety that has yielded higher than local Turkey wheat in Kansas and adjoining states, has yielded less than the local Turkey wheat at Waterville, where rust is not a factor. The station has received a number of inquiries as to the advisability of growing this new variety.

Three years' results are available from experiments to determine the value of harrowing winter wheat in the spring. Compared with ground not harrowed, the yields of the harrowed plats have been reduced from one to more than two bushels per acre—varying with the time of harrowing. As a direct result of this work, the practice of harrowing winter wheat was discontinued in 1921 on farms within a radius of ten miles of the experiment station.

The new methods of treating wheat with powdered copper carbonate and powdered bluestone were tried in 1921. Each of the dry treatments controlled smut better than the common method of dipping the seed in a solution of one pound of bluestone to five gallons of water.

A double rod weeder, for controlling weed growth on the summer fallow, was the greatest attraction on the station

in 1921. This type of weeder has been used for some time in other states, but was first demonstrated in North Central Washington by the Waterville Station. At least 100 of these weeders were made by farmers after seeing the demonstrations.

About 300 visitors were present at the Second Annual Field Day held at the station on July 9th. In addition to local visitors, farmers and their County Agriculturists were present from all adjoining counties. Much credit for the success of this day is due to the hearty co-operation of the Waterville Chamber of Commerce and the local County Agent.

THE WASHINGTON IRRIGATION EXPERIMENT STATION

R. P. Bean in Charge

Crops Grown in 1921:

One hundred and sixty-five of the 203 acres owned by the Washington Irrigation Experiment Station were irrigated and cropped in 1920. Because of the extra water required by the 51.5 acres of spring seeded alfalfa the remaining 38 acres of uncropped land were fall seeded to wheat and not irrigated until the spring of 1921.

The entire farm was irrigated and cropped in 1921. Alfalfa on 71 acres produced 385 tons of hay and a fourth crop seven to eight inches high was pastured by lambs. The first cutting of sweet clover on 22 acres yielded 25 tons of hay and the later growth was used for seed, pasture and soil improvement. One hundred and fifty tons of silage were harvested from 25 acres of corn. The remaining land was cropped as follows: 15 acres in peas were reseeded to winter vetch as a green manure crop for corn in 1922, 16 acres in winter wheat were cut for grain. Eight acres were seeded to winter vetch following rye and seven acres of very sandy soil were left in volunteer rye. Also 15 acres seeded to alfalfa and seven acres to sweet clover in the

spring were reseeded in the fall on account of wind damage and shortage of water.

Development of Irrigation System:

Approximately 1700 feet of six and one-eighth inch flume and 550 feet of temporary ditch were constructed on fields irrigated this year for the first time. Most of this area will be cropped uniformly with alfalfa for several years to prepare the soil for experimental use. When the permanent experimental plots are located there a more complicated irrigation system will be required. Some additional leveling was done on this area after the wheat crop was removed in order to correct faults which irrigation had indicated would be objectionable when the fields are re-divided. Some minor improvements were made on several fields to facilitate irrigation and conserve water.

General Improvements:

A wooden hoop, hollow wall silo, 14 by 42.5 feet, and six individual hog houses 7 by 8 feet, were built this year. Two tent frames, built so that the siding can be completed and shingle roofs added, furnish additional housing facilities for farm help. The well was cased deeper to shut out surface water. The painting on all farm buildings was completed; some of these had previously received only the priming coat. A half-mile of barb wire fence was built on the north line in co-operation with the owner of the adjacent land. A similar fence of the same length is under construction on the west boundary. Alfalfa pasture and feed lots for hogs were enclosed with hog fence and panels. More trees were planted for shade and windbreaks, some of these replacing those destroyed by rabbits.

Equipment Purchased:

The major items of equipment purchased during the year include a grain binder, corn binder, silage cutter, manure spreader, hay derrick and sleds, fresno and a set of harness. The shop was equipped with general carpenter and blacksmith tools. One mule and one horse were added, making a total of two horse and two mule teams on the farm.

Major Cropping and Livestock Problems:

Alfalfa hay is grown on such a large scale in irrigated Washington that the net returns are frequently less than might have been secured had a portion of that acreage produced other crops. Many farmers have observed that the yield of alfalfa per acre is decreasing on fields from which hay has been sold year after year and no fertility returned to the soil. This situation presents three major problems: the use of fertilizers, crop rotation and crop marketing. With these problems in view, experimental crop rotations will be established on the station and a study will be made of crops and varieties best adapted to rotations on irrigated land. Crops produced on the farm are being marketed through livestock whenever practicable and the manure is applied to the land. Additional data will be secured by growing and fattening the livestock by different methods and rations. This comprehensive plan affords opportunity for study and demonstration of most factors of crop and animal production and marketing which are within the farmers' control.

The livestock program was begun by the purchase of 36 yearling steers at the Spokane Stock Yards in November, 1919. These steers were wintered on straw, corn fodder, stubble pasture and a small amount of hay. They grazed bunch grass from early spring until July 1 and were pastured on sweet clover, rye, and fourth-crop alfalfa until snowfall. Silage and hay were fed in the feed lots from that time until the steers were sold. The experience with these steers was similar to that of most cattlemen who produced beef during the period of a falling market. The financial loss was minimized by growing the steers as economically as possible on cheap feed and not attempting to finish them with high-priced grain. The plan of feeding steers in 1921-22 was abandoned when market conditions indicated a questionable margin of profit for the operation and because of the absolute necessity of safeguarding station

funds at this time. Steers will be fed on the station whenever practicable in the future.

In February, 1921, five pure-bred sows were purchased from the Department of Animal Husbandry of the State College with which to establish a herd for experimental feeding and to utilize farm crops.

A study of the practices of growing and fattening pigs on alfalfa pasture supplemented with grain will be begun in 1922.

In October, 1921, 1675 cut-back lambs averaging 60 to 66 pounds each were purchased. They were pastured on alfalfa fields until snowfall, when they were sorted into uniform groups and placed in 19 feed lots for experimental feeding. The projects of this feeding trial are: The Proportion of Grain to Alfalfa Hay for Fattening Lambs; the Comparative Feeding Value of the First, Second, and Third Cuttings of Alfalfa Hay; Hay vs. Hay and Silage; Grain vs. Grain and Molasses; Grain vs. Grain and Cottonseed Meal. The lambs will be fed from 60 to 100 days, depending upon the rate of gain, finish and market conditions.

Experimental Work with Farm Crops:

The work with Farm Crops at the Irrigation Station up to the present year consisted largely of getting fields into condition to carry on experimental work. H. P. Singleton was appointed to conduct experimental work in farm crops and reported at the station May 16, 1921.

Varietal experiments with alfalfa were conducted in four adjoining fields, the stand of which was two years old. Triplicate 1/20 acre plots were laid off in each field and the yield of each plot was found for each cutting. The following table gives the average total yield per acre of the plots in each field for 1921:

Variety	No. of Cuttings	Acre Yield in tons	Height of Pasture Nov. 14
Common (Dakota)	3	6.8	8 in.
Common (Kansas)	3	6.3	10 in.
Common (Local)	3	5.9	10 in.
Turkestan	3	5.2	Dormant

The growing period of Turkestan Alfalfa apparently is too short for the long growing season of the Yakima Valley. It becomes dormant before the growing season is over, resulting in a light third cutting and no fall pasture.

An experiment on the time of cutting alfalfa was started and the results for 1921 are given below.

Stage of bloom	Date 1st Cutting	Date 2nd Cutting	Date 3rd Cutting	Total Acre Yield
0-1/4 in bloom.....	June 10	July 2	Sept. 17	6.8
1/2 in bloom.....	June 16	Aug. 1	Oct. 3	7.5
3/4—full bloom.....	June 23	Aug. 10	Oct. 19	8.0

These results are contradictory to the popular belief that alfalfa must be cut before the new growth is tall enough to be clipped by the mower, and tend to show that the time of cutting should depend upon the stage of maturity at which the greatest amount of palatable hay can be obtained. The experiment will be continued.

Sunflowers were grown in 1921 in an experiment to determine the distance between rows and the spacing in the row at which the greatest amount of silage can be obtained. The following table gives the results:

Plot No.	Dist. bet. Rows	Spacing in Row	Acre Yield in Tons
1.....	30 in.	12 in.	8.5
2.....	30 in.	18 in.	7.4
3.....	30 in.	24 in.	6.5
4.....	36 in.	12 in.	8.1
5.....	36 in.	18 in.	5.0
6.....	36 in.	24 in.	5.9
7.....	42 in.	12 in.	5.9
8.....	42 in.	18 in.	5.6
9.....	42 in.	24 in.	4.9

The highest yield was obtained in the plot having the least distance between the rows and plants. A 6-inch spacing will be included in this experiment in 1922.

The variety tests with cereals were seeded on new ground and the stand was so thin and short that the binder could get only a small portion of the grain. Rabbits completely destroyed the varietal tests with peas, soy beans and cow peas. These circumstances will be guarded against in 1922 by conducting the cereal tests on land that has grown alfalfa and by rabbit-proof fencing.

Experimental Work with Potatoes:

Experiments in seed potato production to determine if possible methods that may be used for growing seed potatoes in the irrigated valleys and what districts are best suited for the production of seed potatoes for irrigated areas were commenced in 1920 as a part of the seed potato project of the main Experiment Station. Potatoes grown at Prosser and at Pullman were planted in plots at each station so that yields at the two places could be compared. The Earliest of All and Netted Gems were used in these tests. The relative productivity of the various strains appeared to be the same in the two localities. There is some small indication that the material produced at Prosser was not as good seed material as that produced at Pullman but another season's results might be entirely different. It is the plan to conduct the work the coming season by planting materials from the same original sources at each station.

The Experimental Orchard:

Six acres of well selected land on the station will be planted to an experimental orchard in the spring of 1922. The trees have been hand selected and consist of Winesap, Delicious and the Red Rome Beauty. This orchard will be used for the study of water requirements, systems of tillage, cover crop management and the general development of an orchard. It may also serve in the years to come as a basis for studies of orchard pests and their control. These investigations to be effective should be reinforced by extensive studies in the practical commercial orchards of the principal orchard sections of the state.

Irrigation Studies:

Before irrigation studies could be commenced it was necessary to have the station fields in such shape that some of them could be used for this purpose. This stage of development has now been reached and definite studies in the methods of application of water and of water require-

ments for various crops on the different soils represented on the station farm will be commenced the coming season.

How to get a maximum crop with a minimum amount of water is a major problem in almost every irrigated section. Methods of water application, water requirements of various crops, water distribution systems, leaching, soil building and the maintenance of fertility, alkali as a result of irrigation, etc., are but different parts of this problem. To secure helpful information on all of these questions will require many years of careful work. While it is hoped that interesting and helpful results may be secured each year, these investigations, to be of the largest service, must extend over a comparatively long period of time. In addition they need to be reinforced by tests and demonstrations on practical farms in the irrigated section.

FINANCIAL STATEMENT
WASHINGTON AGRICULTURAL EXPERIMENT STATION

in account with

THE UNITED STATES APPROPRIATIONS, 1920-1921

Dr.	Hatch	Adams
Receipts from the Treasurer of the United States as per appropriations for fiscal year ended June 30, 1921, under acts of Congress approved March 2, 1887 (Hatch fund), and March 16, 1906 (Adams fund).....		
	\$15,000.00	\$15,000.00
Cr.	Abstract	
By Salaries	1 \$ 8,667.82	\$11,884.57
Labor	2 3,277.87	1,704.12
Publications	3 1,600.79	
Postage and stationery	4 71.06	7.00
Freight and express	5	
Heat, light, water and power	6	60.75
Chemicals and laboratory supplies	7 5.40	464.86
Seeds, plants and sundry supplies	8 467.71	5.17
Fertilizers	9 9.03	3.75
Feeding stuffs	10	
Library	11 18.00	10.00
Tools, machinery and appliances	12 96.15	30.66
Furniture and fixtures	13 389.15	
Scientific apparatus and specimens	14 66.50	465.17
Live stock	15	
Traveling expenses	16 262.57	363.95
Contingent expenses	17	
Buildings and land	18 67.95	
Total	\$15,000.00	\$15,000.00

FINANCIAL STATEMENT

State Funds Expended on Main Station and All Branch Stations

(Excepting the Western Washington Station, which is operated independently)

April 1, 1920, to March 31, 1921

	Dr.	State Appropriations	Sales	Total
To balance on hand.....			\$ 6,192.81	\$ 6,192.81
Receipts from other sources than the U. S. for the year ended		\$34,580.25	\$12,296.15	\$46,876.40
Total		\$34,580.25	\$18,488.96	\$53,069.21
Cr.				
Salaries		\$17,889.73	\$ 1,250.00	\$19,139.73
Labor		7,035.81	8,108.90	15,144.71
Publications		20.63	714.02	734.65
Postage, stationery, telephone and telegraph.....		651.47	482.92	1,134.39
Freight and express.....	\$	634.66	\$ 149.98	\$ 784.64
Heat, light and water		198.99	33.20	232.19
Chemical supplies		180.02	239.76	419.78
Seeds, plants, sundries		1,208.09	2,149.79	3,357.88
Fertilizers			19.50	19.50
Feeding stuffs		1,039.04	881.13	1,920.17
Library		579.59	6.50	586.09
Tools, machinery and appliances		1,064.19	200.60	1,264.79
Furniture and fixtures		402.98	12.40	415.38
Scientific apparatus		396.24	83.84	480.08
Livestock			75.00	75.00
Traveling expenses		1,701.06	954.01	2,655.07
Buildings and lands		1,577.75	2,530.27	4,108.02
Balance			597.14	597.14
Total		\$34,580.25	\$18,488.96	\$53,069.21

FINANCIAL STATEMENT

Western Washington Station

	Dr.	State Appropriations	Sales	Total
To balance on hand			\$12,537.70	\$12,537.70
Receipts		\$53,180.22	\$30,568.75	\$83,748.97
Total		\$53,180.22	\$43,106.45	\$96,286.67
Cr.				
Salaries	\$	7,793.18	\$15,848.93	\$23,642.11
Labor		8,074.95	13,435.53	21,510.48
Publications		804.48	5,978.36	6,782.84
Postage, stationery, telephone and telegraph.....		866.88	337.98	1,204.86
Freight and express		161.19	244.89	406.08
Heat, light and water		1,335.86	523.31	1,859.17
Chemical supplies		102.10		102.10
Seeds, plant and sundries		4,620.94	839.35	5,460.29
Fertilizers		132.54		132.54
Feeding stuffs		7,716.54	3,558.33	11,274.87
Library		33.50		33.50
Tools, machinery and appliances		820.94	211.79	1,032.73
Furniture and fixtures		431.60	206.50	638.10
Livestock		6,021.38	50.00	6,071.38
Traveling expenses		802.56	586.16	1,388.72
Buildings and lands		13,461.58	382.54	13,844.12
Balance			902.78	902.78
Total		\$53,180.22	\$43,106.45	\$96,286.67

*The report of the work of the Western Washington Station, which is operated independently, is not included in this report.

BULLETINS OF THE EXPERIMENT STATION

GENERAL BULLETINS

1. *Announcements, Dec., 1891.
2. *Report of Farmers' Institute, Held at Colton, Wash., Jan., 1892.
3. *Report of Farmers' Institute, Held at Garfield, Wash., Feb., 1892.
4. *Wireworms, May, 1892.
5. *Report of Farmers' Institute, Held at Pomeroy, Wash., May, 1892.
6. *Horticultural Information, Oct., 1892.
7. *Two Injurious Insects, Jan., 1893.
8. *Common Fungous Diseases and Methods of Prevention, June, 1893.
9. *Sugar Beets, 1893.
10. *Review of Weather and Crops in Washington for 1893, Dec., 1893.
11. *Preliminary Report of a Feeding Test with Swine, Feb., 1894.
12. *Forest Tree Plantation, 1894.
13. *Washington Soils, 1894.
14. *Silos and Ensilage, Nov. 1894.
15. *Sugar Beets in Washington.
16. *Feeding Wheat to Hogs, March, 1895.
17. *Insect Pests of the Garden, Farm and Orchard, 1895.
18. *The Babcock Milk Test, Aug., 1895.
19. *Vegetables, 1896.
20. *Fibre Flax in Washington, 1896.
21. *Susceptibility of Spermophiles to Pathogenic Bacteria, 1896.
22. *Influenza, Oct., 1896.
23. *Some Notes Concerning the Nitrogen Content of Soils and Humus, Oct., 1896.
24. *The Acid Test for Milk and Cream, Oct., 1896.
25. *Pruning Orchard Trees, Dec., 1896.
26. *Experiments in the Culture of the Sugar Beet in Washington for 1895 and 1896, Dec., 1896.
27. *A Few Facts About Insects, Jan., 1897.
28. *Clearing Land, Jan., 1897.
29. *Rational Stock Feeding, Dec., 1896.
30. *Report of Damage to Fruit Trees Caused by the Severe Freeze of Nov. 26-27-28, 1896, Dec., 1897.
31. *Irrigation Experiments in Sugar Beet Culture in the Yakima Valley, Dec., 1897.
32. I. Correction of Babcock Test for Cream. II. Effect of Richness of Cream on Acid Test.
33. *Fiber Flax Investigations, May, 1898.
34. *The Russian Thistle in Washington, May, 1898.
35. *Miscellaneous Injurious Insects, May, 1898.
36. *Insects Injurious to Currants and Gooseberries, May, 1898.
37. *Present Status of the Russian Thistle in Washington, Oct., 1898.
38. *Prunes May, 1899.
39. *The Improvement of Country Roads, Nov., 1899.
40. *Fertilizers, Dec., 1899.
41. *Forage Plants in Washington, 1900.
42. *A New Sugar Beet Pest, 1900.
43. *Rational Stock Feeding, 1900.
44. *Fish Scrap Fertilizers, 1900.
45. *Poison Parsnip in Western Washington, 1901.
46. *Potato Blight and Its Treatment, 1901.
47. *The Variegated Cutworm, 1901.
48. *A Mechanical Ration Computer, 1901.
49. *Alkali and Alkali Soils, 1901.
50. *A Preliminary Report on Glanders, 1902.
51. *Locating Orchards in Washington, 1902.
52. *Planting Orchards in Washington, 1902.
53. *Nursery Stock for Washington Orchards, 1902.
54. *The Formalin Treatment for Wheat and Oat Smut, 1902.
55. *Washington Soils, 1902.
56. *I. Spraying for the San Jose Scale with Modifications of the Sulphur-Salt-Lime Wash. II. Chemical Notes on the Sulphur-Salt-Lime Wash, 1903.
57. *A Home Vegetable Garden in the Palouse Country, 1903.
58. *Experiments in Feeding Swine, 1903.
59. *Root Diseases of Fruit and Other Trees Caused by Toadstools, 1903.
60. *A Report of the Range Conditions of Central Washington, 1904.
61. *A Report on Irrigation Conditions in the Yakima Valley, Wash., 1904.
62. *The Raspberry-Cane Maggot, 1904.
63. *The Raspberry-root Borer, or the Blackberry-crown Borer, 1904.
64. *The Apple Scab in Western Washington, 1904.
65. *Three Common Insect Pests of Western Washington, 1904.
66. *Blackspot Canker, 1904.
67. *I. Some Notes Concerning Halphen's Test for Cotton-Seed Oil. *II. Reaction of Lard from Cotton-Seed-Meal-Fed Hogs with Halphen's Reagent. *III. Effects of Feeding Cotton-Seed Meal Upon the Health of Animals, 1905.
68. *The Wormy Apple, 1905.
69. *Preliminary Report on the Codling Moth in the Yakima Valley, 1905.
70. *The Powdery Mildews of Washington, 1905.
71. *Preserving Eggs, 1905.
72. *The Chemical Composition of Washington Forage Crops (First Report), 1905.
73. *Feeding Wild Plants to Sheep, 1906.
74. Two Insect Pests of the Elm, 1906.
75. *Apple Scab in Eastern Washington, 1906.
76. *The Economical Preparation of the Sulphur-Lime Spray, 1906.
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165. An Investigation of Sulfur as a Plant Food, May, 1921.

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STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISION OF PLANT PATHOLOGY
AND
AGRICULTURAL ENGINEERING

The Dusting of Wheat for Bunt or Stinking Smut

BY
F. D. HEALD AND L. J. SMITH

BULLETIN No. 168
June, 1922

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THE DUSTING OF WHEAT FOR BUNT OR STINKING SMUT

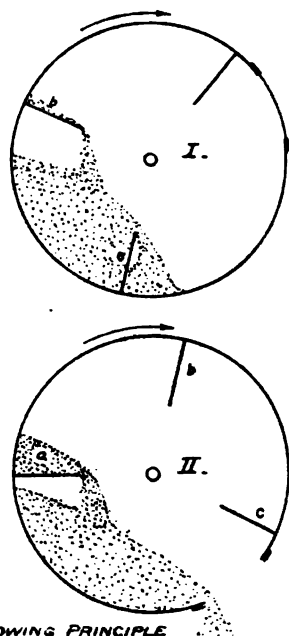
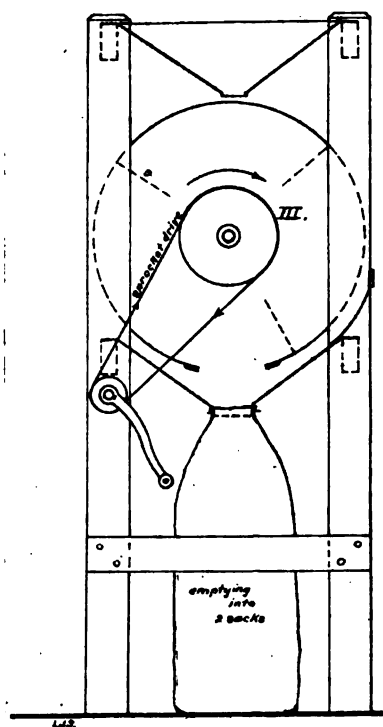
By F. D. Heald and L. J. Smith

INTRODUCTION

In the control of wheat smut we have passed through two periods: first the bluestone or copper sulphate period from the earliest times up to 1897, when formaldehyde was first employed; and second, the formaldehyde period from 1897 to the present time. Although the formaldehyde disinfection has very largely replaced the use of bluestone in the eastern United States, the latter has continued to be used quite extensively in the Pacific Northwest since it has been shown to have some effect in reducing the smut in winter wheat due to soil contamination, while formaldehyde has no residual action.¹ Although both bluestone and formaldehyde treatments have proved effective in preventing bunt of wheat due to seed-borne spores, both have certain disadvantages and their employment is frequently followed by injurious effects upon the crops.

Disadvantages of and Objections to the Standard Wet Treatments

It has long been recognized that the use of the various bluestone formulae² causes much reduction in the percent of germination of treated wheat. Even with close attention to standard recommendations, treated seed may frequently show as low as only 25 to 35 per cent viable, while reductions to 40 or 60 per cent viable are rather common. In addition to the killing effect of the bluestone, there may be a pronounced retardation of growth and a lowered vitality. Young seedlings may be twisted and crippled and the toxic effects persist or are only slowly outgrown. When first introduced formaldehyde was eagerly accepted as a substitute for bluestone since it was claimed to do away with the seed injury. It had the added recommendation of being cheaper and also more convenient, since it is a solution of gas in water and ready to use by diluting to the proper strength. With continued use formaldehyde has also been found to have injurious effects. The reduction in germination per



SHOWING PRINCIPLE
OF

W.S.C. SMUT-TREATING MACHINE.

Designed and built by Agricultural Engineering Dept.,
AGRICULTURAL EXPERIMENT STATION.

Fig. 1. Machine showing the principle of the smut-treating machine. Patents applied for by the Washington Experiment Station, State College.

cent of the treated grain may be very slight, especially if the seed is planted at once in a moist soil, but injury is much more pronounced if the seed is allowed to dry before seeding or if it is seeded in dry soil² where it must wait for rains before germination.

It has long been known that an afterbath of bluestone-treated wheat with milk of lime greatly lessens the amount of seed injury, and it has recently been shown that the same method is effective in lessening the injury from formaldehyde². The work of Braun³ in 1920 showed that pre-soaking would accomplish the same results. While these methods reduce the seed injury and have been recommended for general use, they do not entirely eliminate the depressing effects of the bluestone treatment.

The methods of steeping grain in bluestone or in formaldehyde are inconvenient. The handling of the wet sacks of grain is a disagreeable operation, while the necessity for immersing in two successive baths is an added burden. The necessity for treating grain shortly before seeding, with special precautions concerning drying, makes both of the wet treatments objectionable. The nature of the disinfection has called for the more laborious open-tank method when the seed was heavily smutted. Grain treated by a wet method must also be protected from freezing.

Historical Statement Concerning the Use of Copper Carbonate

Copper carbonate as a fungicide for seed disinfection had been disregarded as its extreme insolubility in water was thought to exclude the possibility of effective action. In the form of a finely powdered dust it was first tested by Darnell-Smith⁴ in New South Wales as a fungicide in the control of wheat smut. On the basis of tests conducted in 1915 and 1916 he reported in 1917 that copper carbonate dust gave better results than either formaldehyde or bluestone. A more complete report was issued in 1919, with the claim that machine-treated grain was free from smut while hand-treated grain showed a slight amount of smut. The copper carbonate dust treatment caused no injury to seed or to young plants and also resulted in very substantial increases in yield⁵. The results of Darnell-Smith were questioned by Perkins⁶ in 1919 who stated that "we can not, for instance, imagine that a substance wholly insoluble in

water can have high fungicidal properties." A discussion of this criticism was published by Darnell-Smith⁷ in 1921.

The excellent results obtained in Australia soon attracted the attention of American investigators. Mackie and Briggs⁸ first reported experiments in California which corroborated the reports from Australia. They reported in 1921 that spring wheat treated with 2 ounces of copper carbonate dust per bushel was free from



Fig. 2. View of machine and wagon with sack of wheat being emptied into the drum.

smut and suffered no reduction in germination, while the untreated check gave 6.2 per cent of smutted heads.

Lambert and Bailey⁹ have just recently reported perfect control of both bunt of wheat and smut of oats by using 2 ounces of copper carbonate dust per bushel. No reduction in germination of oats

resulted from using 2 ounces per bushel, while 2 to 10 ounces of the copper carbonate caused no appreciable injury to wheat.

Comparative Seed Treatments

Since the favorable results reported by other workers have been substantiated by our own experiments, it has seemed advisable to issue this preliminary report in order that the wheat growers of our state may have our recommendations available before the time of seeding winter wheat.

In our preliminary experiments two varieties of wheat, Bluestem and Jenkins Club, were selected for test. The grain was artificially smutted, using 1 gram of smut to each 100 grams of seed. This is the amount of smut determined by previous experiments as necessary to cause fairly heavy smut but not the maximum amount. The smut was applied by shaking smut and seed together in a large jar; after which the smutted seed was divided into smaller lots, each of which received one of the treatments specified. Each lot was planted in the field in rod rows of carefully spaced seed, and greenhouse germination tests were made to determine the amount of seed injury from the respective treatments. Head and plant counts of the field plots were made at harvest time.

TABLE I.
Comparison of Dust and Wet Seed Treatments

Treatment	BLUESTEM			JENKINS CLUB		
	Per cent germination	Per cent smutted plants	Per cent smutted heads	Per cent germination	Per cent smutted plants	Per cent smutted heads
Check, untreated	84.25	15.06	13.6	89.5	4.5	3.2
Bluestone, wet	67	0	0	65.5	1.2	0.4
Formaldehyde, wet	38.5	0	0	53.5	1.1	0.7
Chlorophol, wet	94.5	0	0	96	0	0
Copper carbonate 2 oz. Dust	91.5	0	0	92	0	0
Copper carbonate 4 oz. Dust	98.5	0	0	96.5	0	0
Copper sulphate+) calcium carbonate) (equal parts)						
2 oz. Dust	92.5	0	0	94.5	0	0
Sulphur, 10 lbs. "	89.	0.5	0.2	92.	0	0
Sulphur, 20 lbs. "	94.	0	0	93.5	0	0

The relatively low per cent of smut in both of the checks is explained by the high temperatures and dry conditions immediately

following planting, while the smaller amount of smut in the Jenkins Club plots was due to the proximity of these to a row of willow trees which drew very heavily on the soil moisture. It may be noted that perfect control of the smut was obtained by copper carbonate dust and also by the mixture of finely powdered anhydrous copper sulphate (bluestone) and powdered calcium carbonate. The latter mixture will result in the formation of copper carbonate as soon as the



Fig 3. View with drum of machine in position to show the opening and one of the radial mixers or buffers.

treated grain comes in contact with soil moisture and would therefore be expected to give results similar to an initial application of copper carbonate dust. It must remain for further tests to determine the practicability of using this cheaper mixture as a substitute for copper carbonate. The dust treatments have given an improved germination of the wheat when contrasted with the bluestone and formaldehyde disinfection. The value of sulphur dust in smut control is still open to question. Even if it should continue to give the

protection as indicated by these tests, increased yields would be necessary to justify the expense of using the large amount of sulphur necessary.

Equally good results with the copper carbonate dust have been obtained at the Waterville Branch Experiment Station as reported by Mr. C. E. Hill. Untreated seed gave 86 per cent smut as contrasted with 0.5 per cent from seed treated with 2 ounces of copper carbonate per bushel. The demonstrations at a number of points in the state as reported by Mr. G. L. Zundel, Extension Plant Pathologist, have also shown the superiority of copper carbonate in smut control.

The question has been raised as to whether wheat may be dusted with copper carbonate some months previous to seeding time without suffering any injury. In order to test this point four varieties were given the standard treatment (2 ounces per bushel), and germination tests made at intervals in comparison with untreated seed. The treated and untreated seed was planted in flats in the greenhouse, using 200 seed in each lot. The appended table shows the results obtained up to the present time (Table II).

TABLE II.

Showing Germination per cent of Untreated and Dusted Seed of Several Varieties of Wheat

Date of test	Jenkins Club		Hybrid 128		Marquis		Jones Winter Fife	
	Untreated	CuCO ₃	Untreated	CuCO ₃	Untreated	CuCO ₃	Untreated	CuCO ₃
Feb. 7	85	88.5	87.5	92.5	89.5	94.5	95	90.5
Mar. 8	67.5	90	75	60	96	85	91	96
Apr. 15	81.5	*	80	*	84	*	92	*
May 8	76	95	79.5	89.5	77	96	84	96
June 24	77	84.5	80.5	81.5	82.5	91.5	87.	92.

*Plants destroyed by mice.
CuCO₃ is Copper Carbonate

An examination of this table will show not only that no injury resulted for the duration of the test, but that the dusted grain showed an improved germination over the untreated samples.

Mr. Hill, of the Waterville Branch Station, has reported the value of copper carbonate in lessening seed injury for late fall-seeded grain. The data in the appended table (Table III) are taken from his report.

TABLE III.
Germination per cent of Fall-Seeded Wheat

Treatment	Per Cent of Germination		
	Hybrid 128	Turkey	
Untreated seed	90	95	
Formaldehyde 1-80	86	45	
Formaldehyde 1-60	63	70	
Bluestone 1-5	40	52	
Copper carbonate 2 oz. dust	90	95	

Specific data concerning the comparative value of copper carbonate dust and the standard bluestone treatment in preventing smut from soil contamination will not be available until the end of the 1922 harvest.

Preliminary tests, however, indicate that the carbonate dust will be much more effective. Copper sulphate is very readily soluble in the soil moisture and is quite rapidly removed from the vicinity of germinating grains, while copper carbonate is very slowly soluble and should therefore have a more persistent effect.

Formula and Methods of Application of Copper Carbonate Dust

On the basis of completed trials our present recommendation is the use of 2 ounces of finely powdered copper carbonate, testing 50 per cent or more of metallic copper, per bushel of wheat. The powder should be fine enough to pass through at least a 100-mesh sieve. The effectiveness of the treatment depends on the uniform distribution of the finely divided particles over the surface of the grain. Two ounces per bushel gives a complete coating, and no added protection has been afforded by using 4 ounces per bushel. Work now in progress will tell whether it will be possible to use less dust per bushel and still obtain effective protection.

The application of the copper carbonate dust may be made in a number of different ways. In our earliest experimental work the treatment was carried out by shaking the seed and the requisite amount of copper carbonate in a closed container. A barrel churn has been used with good results, while in some larger operations a small concrete mixer has been tried. In some of the demonstration trials the dusting has been accomplished by emptying the wheat and the desired amount of copper carbonate on a canvas and shoveling



Fig. 4. View of machine with the two sacks partially filled. A second lot is treated before the sacks are ready to be removed.

over the mixture until the grain became thoroughly coated, but this last method is not recommended as it is felt that it gives the least effective distribution of the dust and offers more opportunity for persons doing the treating to inhale the irritating and poisonous dust particles. A special dusting machine has been designed which is effective and also convenient, and it is expected that this or a similar machine will come into general use.

Washington State College Smut-Treating Machine*

In designing a machine for the dry or dust treatment of wheat for smut the following points were kept in mind: (1) To handle the grain as little as possible; (2) To mix the grain and copper carbonate in sack lots; (3) To make the machine self-bagging; (4) To sack the



Fig. 5. View of the small dusting machine, which is arranged to empty into a box or tray.

grain in quantities that could easily be handled at the drill; (5) To mix the grain with as few turns of the drum as would give effective distribution; (6) To avoid the disagreeable copper carbonate dust; (7) To build a machine that a farmer having mechanical ability might make.

The accompanying illustration (Fig.1) shows the principle of the mixer. The drum is revolved until the opening is under the fill-

*Patents Applied for.

ing hopper. A stop bolt through the vertical post holds the drum in filling position. The helper on the wagon then empties a sack of grain into the hopper and it flows into the drum. (Fig. 2). The drum is then turned back so the operator standing on the ground can scatter the copper carbonate uniformly over the surface of the grain, after which the sliding door is put in position and the drum rotated for two minutes. This gives 20 to 30 revolutions per minute which is sufficient to coat thoroughly each grain with the powder.

In the drum there are three wooden radial mixers or buffers, of a width equal to half the radius of the drum (Figs. 1, 3). In position I the grain has slid off the board "b" and is being lifted by "a," during which time it flows over "a" like water over a dam. It should be noticed that the upper portion of the grain is passing over "a" first. Position II shows the bottom portion of the grain leaving "a" and forming the top of the pile below. Thus the grain is largely reversed in position each time it passes over a mixing-board, making three mixes per revolution of the drum. When the two-minute mixing period is completed, the drum is stopped at its filling position, and the sliding cover is pulled out. The drum is then turned one-half a revolution to position III at which position the treated grain is equally dumped into the two sacks below and is ready to be tied up for use in the field. (Fig. 4).

The ratio of the sprockets is 1 to 4, there being 6 teeth on the drive sprocket and 24 on the drum sprocket. The drum is 21 inches in diameter and 36 inches long. The machine stands five and one-half feet in height. The machine has a capacity of one full sack of wheat, but it is expected that partial sacks ($1\frac{1}{2}$ bushels) will be used. In treating a sack of wheat, the crank turns by hand about as hard as a cream separator. One sack can easily be run through every four or five minutes. It would therefore not take long to treat enough seed for a large field.

A blueprint showing all the dimensions of the smut-treating machine will be sent upon application, with a covering fee of twenty-five cents.

The first machine made to test the utility of this principle of mixing is shown in Fig. 5. The drum is 16 inches in diameter and 24 inches long. It was built as an investigational study in Agricul-

tural Engineering by a student, Stephen White, whose ideas assisted very materially in the development of the larger machine. The small mixer will treat one-half bushel at a time. It is about as large as can be conveniently turned with the crank fastened to the axle of the drum, and would do very well for treating seed for small fields.

Advantages of the Copper Carbonate Treatment

The advantages of the dust treatment are so pronounced that this method of control may be expected to replace the older wet treatments with bluestone or formaldehyde. It is our prophecy that we are now beginning the "copper carbonate dust period of seed disinfection." The important advantages of this copper carbonate dust may be briefly enumerated as follows:

1. The elimination of the inconvenient and disagreeable soaking methods.

2. The convenience of being able to treat seed days or even months before it is needed for use, thus making possible the utilization of spare time.

3. The elimination of seed injury and retarded growth, with even an improvement in germination over that of untreated seed. This will make possible a reduction in the amount of seed used per acre and should result in a considerable annual saving as soon as the method comes to be generally practiced.

4. The elimination of danger from seeding in the dry, making it possible to seed in the "dust," rather than being obliged to wait for rain.

5. Probable increased yields due to better stands, no retarding influence of the fungicide, and better control of smut.

6. A probable increased protection from reinfection of treated seed by smutty sacks, broken smut balls or from the wind-borne spores that are generally present in our summer fallow fields.

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STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISION OF ANIMAL HUSBANDRY

Hog Feeding Experiments

By
H. Hackedorn and J. Sotola



BULLETIN NO. 169
August, 1922

All Bulletins of this Station are sent free to citizens of the State on application to the Director

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Hog Feeding Experiments

INTRODUCTION

The State of Washington and adjacent States do not produce sufficient pork to supply the demand within this territory. All of the larger butchers and packers testify that pork has to be shipped in to meet the fresh-meat demand. Evidence of this condition is reflected by the fact that the price of hogs on foot at the Union Stockyards, Spokane, during the last two years ranged from 1 to 3 cents above the price for similar grades at the Union Stockyards in Chicago. It is apparent that the market for hogs in this territory is good.

Crops such as barley, wheat, corn, peas, etc., all suitable for hog feeds, are grown successfully in this State. At the main experiment station, Pullman, the average yield of barley for the last six years has been 3,115 lbs. per acre, which is 634 lbs. more than the average for spring and winter wheat for the same period. Barley and wheat have a feeding value practically equivalent to that of corn. Corn, as a grain crop, is grown successfully in some of the irrigated sections. Alfalfa and peas are used extensively as forage crops and aside from furnishing a superior forage for hogs, they aid in conserving nitrogen of the soil.

PRINCIPLES OF NUTRITION UNDERLYING HOG FEEDING

If best results are to be obtained from feeding operations every possible saving in the cost of production must be made.

Hogs have certain physiological requirements which must be met to produce the maximum economic gains. These requirements call for certain quantities of digestible protein, energy, mineral matter and vitamins. In practice today only the first three receive much consideration. The energy of a ration must come either from digestible proteins, carbohydrates or fats. From the economic standpoint it is highly desirable that the energy come from the inexpensive carbohydrates and fats rather than from the expensive proteins.

Balanced rations contain each of these nutrients in proper proportion, form and quantity. By proper form reference is especially made to digestibility and bulk. A chemical analysis may indicate that a ration contains the required proportion and quantity of nutrients,

but if these are in a highly indigestible form they cannot satisfactorily meet the physiological requirements of the animal. If these nutrients are supplied in the form of bulky feeds, then the hog cannot consume enough feed above that necessary for maintenance to make satisfactory gains. In other words, feeding an excessively bulky ration to a pig is equivalent to restricting the ration.

The cereal grains, corn, barley, and wheat, are unbalanced for hog feeding. Their content of digestible protein and ash is too low for the attainment of best results. It is necessary to supplement such grains with protein rich feeds. These feeds are characterized by a high content of suitable and digestible protein per unit of bulk. They must generally be purchased and, because of high freight rates, it is desirable that they contain the maximum percentage of protein and maximum quantities of fats and carbohydrates. The last two are produced easily and in abundance on the farm. With this condition obtaining, a smaller tonnage per unit of protein makes the feed more economical if it must be shipped any considerable distance.

Other factors to be considered in connection with this class of feeds are, keeping quality, availability, ash content, palatability, effect on quality of product, and last, but not least, the cost per unit of protein.

It is a matter of common observation that young pigs make more economical gains than older ones. This is explained on the basis of differences in energy content of gains made at these respective ages. Young pigs at birth are largely composed of water and protein, and in the early stages of their development gains in weight consist mostly of protein and water, and very little energy. It is during such a period that pigs require a ration with a high protein content. After the muscular structure is somewhat developed, the succeeding gains are largely fat deposited in the adipose tissue and around the internal organs. These latter gains have a high energy value.

As the pigs mature, the protein requirement becomes less, and the ration should be adjusted accordingly, by decreasing the quantities of protein rich feeds in the ration. Thus the gains are made more economically by reducing the consumption of expensive constituents with little material effect upon the gains. Too little protein will reduce the efficiency of the entire ration, while too much of it does not increase the production sufficiently to justify the expense.

THE FEEDING TESTS

Object of the Feeding Tests

The series of feeding tests discussed under Part I, were planned to compare the feeding value of two protein rich feeds, fishmeal and "Digester" tankage. Part II includes the results of studies involving the best method of feeding cocoanut meal. Results with linseed oil

meal are discussed in Part III. The value of cane molasses in terms of barley is discussed under Part IV. Alfalfa and field peas for pork production are treated in Part V.

Grain Mixtures

In all the feeding trials here reported, the grain mixtures have been adjusted to supply a sufficient but not an excessive amount of protein. The modified Wolff-Lehmann feeding standard was used as a guide in calculating these rations.

As the pigs gained weight the mixtures were varied, the proportion of supplement being decreased. The mixtures, fed the pigs at the different weights, are recorded in Tables I and II.

TABLE I

Grain Mixtures Fed in Dry Lot Containing Tankage, Fishmeal and Cocoanut Meal As Protein Supplements.
(Years 1918-19-20)

Range of Wts. of Pigs Re- ceiving Mix- ture (lbs.)	Feeds	Parts by weight fed during tests.			
		Tankage	Fishmeal	Tankage	Cocoanut Meal
70-90	Barley	105	105	55	105
	Millrun	35	35	35	.....
	Tankage	20	.....	20	20
	Fishmeal	.....	20	.....	.....
	Cocoanut Meal	.....	.....	.....	35
	Molasses	.....	.....	70	.....
90-130	Barley	27	27	14	27
	Millrun	9	9	9	.....
	Tankage	4	.....	4	4
	Fishmeal	.....	4	.....	.....
	Cocoanut Meal	.....	.....	.....	9
	Molasses	.....	.....	21	.....
130-200	Barley	12	12	6	12
	Millrun	4	4	4	.....
	Tankage	1	.....	1	1
	Fishmeal	.....	1	.....	.....
	Cocoanut Meal	.....	.....	.....	4
	Molasses	.....	.....	9	.....

TABLE II
*Grain Mixtures Fed During Winter 1921-22**

Range of Wts. of Pigs Re- ceiving Mix- tures.	Feeds	Parts by weight fed during tests.				
		Tankage	Fishmeal	Linseed Meal	Linseed Meal Tankage	Linseed Meal Fishmeal
40-75	Barley	150	150	150	150	150
	Millrun	50	50	50	50	50
	Tankage	44	.....	.....	22.5	.....
	Fishmeal	.....	38	.....	.....	22
	Linseed Meal	.....	.....	62	22.5	22
75-125	Barley	150	150	150	150	150
	Millrun	50	50	50	50	50
	Tankage	26	.....	.....	15	.....
	Fishmeal	.....	21	.....	.....	13
	Linseed Meal	.....	.....	36	15	13
125-175	Barley	150	150	150	150	150
	Millrun	50	50	50	50	50
	Tankage	12	.....	.....	8	.....
	Fishmeal	.....	14	.....	.....	9
	Linseed Meal	.....	.....	20	8	9

*The mixtures are only slightly different from those used in previous tests. Since the pigs were started on feed at a lighter weight the mixtures contain a greater proportion of the supplement. The mixtures for any specific weight of pigs contain the same quantity of digestible protein per hundredweight.

Method of Feeding

In all the feeding tests, whether in dry lot or on forage, the hogs were hand-fed twice daily, the morning feed being given at about 7:30 a. m., and the evening feed at 4:30 p. m. The rations were fed in the form of a fairly thick slop, being mixed with water at the time of feeding. The troughs were never filled to excess, so that little feed was ever wasted.

In the dry lot feeding tests with hogs on full feed, the quantity of grain fed was adjusted to the appetites, the hogs being fed all they would consume without waste. All lots had free access to water.

The hogs in dry lot during 1921-22 were fed a mineral mixture in self-feeders. The mixture consisted of 5 parts, by weight, of finely ground steamed bonemeal, 4 parts, by weight of air-slacked lime, and 1 part of common salt.

Quarters

Shade on forage was provided by means of a canvas stretched over a wooden framework. During the greater part of the dry-lot feeding tests, the hogs were housed in the hog barn in pens connected with outdoor lots. Throughout the last part of the dry-lot feeding in 1920-21, however, the pigs were moved to outdoor lots, with cots for shelter.

All quarters were kept clean and well bedded with straw. Sufficient shelter was provided so that the hogs were not crowded at any time during the experiment.

Weights and Records

Since there is considerable fluctuation in body weight of pigs from day to day as well as throughout the day, all weights were taken at a specified time, in this case after the morning feed between 8:00 and 10:00 a. m.

Individual weighings were recorded so that in case it became necessary to remove pigs from any lot because of sickness or death, the grain consumed by them while on test could be readily subtracted from the total of any lot, in proportion to body weight. All initial and final weights for the entire experimental period are averages of weights taken on three consecutive days. The middle date of each succession marks the beginning or end of the experiment. Throughout the tests all hogs were weighed individually every thirty days. Lot weights were taken at more frequent intervals in order to keep closely in touch with the progress of the tests.

The average initial and final weights and the range of weights of the pigs in the lots to be compared were kept as equal as was practical, the slower gaining lots being kept on experiment longer, in order to accomplish this.

Type of Hogs in Feed Lots

Pure bred Duroc Jersey and Poland China hogs farrowed on the College Farm were used in this series of experiments. The individuals in the various lots were reasonably uniform in respect to size, condition, and feeding qualities. Breed and sex differences were not considered in making the division. The hogs were of medium type, being out of 2 to 4-year-old sows that weighed from 450 to 500 lbs. in medium breeding condition, sired by boars weighing about 150 lbs. more in similar condition.

PART L—(a) TANKAGE VS. FISHMEAL IN DRY LOT AND ON FORAGE

Introduction

The work planned to compare the feeding values of fishmeal and tankage rests on the basis of the values of these feeds when fed with rolled barley and millrun in balanced rations. It is evident that of several lots of pigs receiving the same protein supplement in varying quantities, the lot fed either too small or too large quantities will appear at a disadvantage, when the comparison is made on the basis of pounds of grain consumed per unit of gain.

Six lots of pigs were included in the plan. The lots were fed in pairs on alfalfa forage, pea forage and in dry lot. All lots received rations differing only in the protein supplement used, this being fishmeal in one case, and "Digester" tankage in the other case.

Factors such as initial weights, condition, quantities of feed fed daily, final weights, and kind of forage available were to be maintained as nearly identical as possible for each pair of lots, but conditions did not permit keeping the factors identical for all six lots. The main differences in the average daily gain and in the quantities of feed necessary to produce 100 pounds body gain are then indications of differences in feeding value of fishmeal and tankage.

The quantities of grain fed on forage were to be approximately one-half of those fed in dry lot.

Three parts by weight of steam-rolled barley were mixed with one part of millrun in all the tests, and the supplements were added to balance the rations. Figures in Table I show how the protein supplements were varied as the weights of the pigs increased.

Rolled barley of good quality, was used. The millrun fed contained bran, shorts, and middlings, mixed and finely ground. This feed is too bulky to be used in large amounts, but when of good quality adds to the palatability of the ration; it also makes it more laxative.

The tankage contained 60% crude protein, a small proportion of finely ground bone, and practically no hair or other coarse material. It is commonly called "Digester" tankage, which distinguishes it from the coarser grades used as nitrogen fertilizers.

The fishmeal made from fat-extracted fish trimmings of canneries contained 56% protein, had a dark yellow color, and a characteristic fishy odor. There are numerous grades on the market, which vary in color and protein content. Generally the darker the color the higher is the protein content.

The rations of each of the two lots fed in dry lot were identical in the quantities of barley, millrun, and protein supplement fed. The same is true for the lots on pea forage and on alfalfa. (See last line Table III.)

Table III contains the data for 6 lots of pigs fed to demonstrate any existing differences in the feeding value of fishmeal and tankage.

TABLE III

Tankage Versus Fishmeal in Dry Lot, on Pea Forage and on Alfalfa Pasture.

	Dry Lot		Pea Forage		Alfalfa Pasture	
	Lot I	Lot II	Lot III	Lot IV	Lot V	Lot VI
	Barley Millrun Tankage	Barley Millrun Fishmeal	Barley Millrun Tankage	Barley Millrun Fishmeal	Barley Millrun Tankage	Barley Millrun Fishmeal
No. of pigs	14	14	17	18	7	7
Av. No. of pigs per acre	.....	.....	8	6	11	11
Period of test	Jan. 18- Mar. 15	Jan. 18- Mar. 15	July 19- Sept. 30	July 19- Sept. 30	Aug. 11- Oct. 14	Aug. 11- Oct. 14
Days	57	57	74	74	65	65
<i>Average Weights and Gains (pounds)</i>						
Av. initial wt.	69.641	68.615	65.49	66.40	40.8	40.8
Av. final wt.	144.521	148.473	144.32	146.22	92.9	93.4
Av. total gain	74.88	79.86	78.83	79.82	52.1	52.6
Av. daily gain	1.314	1.401	1.065	1.079	.802	.809
<i>Pounds Feed Per Cwt. Gain</i>						
Barley	298.0	278.4	193.5	196.6	208.2	208.9
Millrun	99.3	92.8	64.4	65.5	69.8	69.2
Tankage	44.0	.....	27.3	.....	42.4	.....
Fishmeal	.....	41.0	.....	24.6	.....	39.5
Total	441.3	412.2	285.2	286.7	320.4	317.6
<i>Average Daily Rations (pounds)</i>						
Barley	3.916	3.901	2.061	2.122	1.67	1.69
Millrun	1.305	1.300	.686	.707	.56	.56
Tankage	.578	.....	.291	.....	.34	.....
Fishmeal	.....	.575	.....	.266	.....	.32
Total	5.799	5.776	3.038	3.095	2.57	2.57

Discussion

Lot I receiving tankage in grain mixtures made an average daily gain of 1.314 lbs. for 57 days, requiring 441.3 lbs. of concentrates to make 100 lbs. body gain. Lot II receiving fishmeal made a daily gain of 1.401 lbs. per head for 57 days requiring 412.2 lbs. of concentrates per 100 lbs. gain. The fishmeal lot consumed 29.1 lbs., or 6.6 per cent. less feed to make 100 lbs. gain.

Lot III on pea forage receiving tankage made an average daily gain of 1.065 lbs. for 74 days and required 285.2 lbs. of grain besides the pea forage to make 100 lbs. body gain. Lot IV on pea forage being fed fishmeal made a daily gain of 1.079 lbs. for a similar length of time, consuming 286.7 lbs. of grain mixture to make 100 lbs. body gain. These results are almost identical as far as daily gains and feed consumed to make these gains are concerned. On pea forage no differences between the feeding value of tankage and fishmeal are noticeable.

Lots V and VI, including seven head of hogs each, made an average daily gain per head of .802 lbs., and .809 lbs., respectively. Lot V receiving tankage consumed 320.4 lbs. of concentrates to make 100 lbs. gain, while Lot VI, fed fishmeal, consumed 317.6 lbs. of concentrates to make the same gain. These two lots were as nearly alike, as might be expected had they both received the same ration. On alfalfa forage, fishmeal and tankage fed in the same proportions gave identical results.

At the end of the tests each of the two lots of pigs were judged for differences in condition of flesh and finish. The fishmeal lot ranked slightly higher, but the difference was so slight that no distinction was made in the prices paid for the two lots.

The comparative feeding tests in dry lot, on pea forage and on alfalfa forage involving 28 head fed 57 days, 35 head fed 74 days, and 14 head fed 65 days, have failed to show any marked difference in these feeds.

Table IV has been compiled from the grain requirements per 100 lbs. body gain of Lots I and III, to furnish a ready reference of the cost of gains with varying feed prices. The cost of 100 lbs. gain is based on feed consumed to make this gain, under the condition of these trials and makes no allowance for labor and other factors.

Table V, following Table IV, was calculated in a similar manner except that the feed consumed per 100 lbs. gain of Lots II and IV are used as the basis.

Tables IV and V demonstrate the similarity in the cost of producing pork when either fishmeal or tankage are used as protein supplements. The grain required to produce 100 lbs. gain in dry lot is greater than when the pigs have access to forage. The cost of grain per 100 lbs. gain in dry lot constitutes the total feed charge. The cost

(Cost Data)—(See Table Contents)

TABLE IV

Cost of Feed Per 100 Lbs. Gain For Pigs Between Weights of 65-150 Lbs.—With Varying Feed Prices in Dry Lot and on Pea Forage.

Cost Per Ton	Lot I Tankage \$50		Lot II Tankage \$60		Lot III Tankage \$70		Lot IV Tankage \$80		Lot V Tankage \$90	
	Dry Lot	Pea Forage	Dry Lot	Pea Forage	Dry Lot	Pea Forage	Dry Lot	Pea Forage	Dry Lot	Pea Forage
Barley \$20	84.58	2.94	84.80	33.08	85.02	33.22	85.24	33.35	85.46	33.49
Millrun 15	4.82	3.10	5.04	3.24	5.26	3.36	5.48	3.51	5.70	3.65
20	5.07	3.26	5.29	3.40	5.51	3.54	5.73	3.67	5.95	3.81
Barley \$25										
Millrun 15	5.57	3.58	5.79	3.72	6.01	3.86	6.23	3.99	6.45	4.13
20	5.82	3.74	6.04	3.88	6.26	4.02	6.48	4.15	6.70	4.29
25	6.07	3.90	6.29	4.04	6.51	4.18	6.73	4.31	6.95	4.45
Barley \$30										
Millrun 20	6.56	4.22	6.78	4.36	7.00	4.50	7.22	4.63	7.44	4.77
25	6.81	4.38	7.08	4.52	7.25	4.66	7.49	4.79	7.69	4.93
30	7.06	4.55	7.28	4.69	7.50	4.83	7.72	4.96	7.94	5.10
Barley \$35										
Millrun 25	7.56	4.87	7.78	5.01	8.00	5.15	8.22	5.28	8.44	5.42
30	7.81	5.04	8.03	5.18	8.25	5.32	8.47	5.45	8.69	5.59
35	8.06	5.20	8.28	5.34	8.50	5.48	8.72	5.61	8.94	5.75

TABLE V

Cost of Feed Per 100 Lbs. Gain For Pigs Between the Weight of 65-150 Lbs.—With Varying Feed Prices in Dry Lot and on Pea Forage.

Cost Per Ton	Lot I Fishmeal \$60		Lot II Fishmeal \$60		Lot III Fishmeal \$70		Lot IV Fishmeal \$80		Lot V Fishmeal \$90	
	Dry Lot	Pea Forage	Dry Lot	Pea Forage	Dry Lot	Pea Forage	Dry Lot	Pea Forage	Dry Lot	Pea Forage
Barley \$20.....	\$4.26	\$2.92	\$4.47	\$3.04	\$4.68	\$3.16	\$4.88	\$3.28	\$5.08	\$3.41
Millrun \$10.....	4.50	3.08	4.71	3.20	4.92	3.32	5.12	3.44	5.32	3.57
20.....	4.73	3.25	4.94	3.37	5.15	3.49	5.35	3.61	5.55	3.74
Barley \$25.....										
Millrun \$15.....	5.20	3.57	5.41	3.69	5.62	3.81	5.82	3.93	6.02	4.06
20.....	5.43	3.74	5.64	3.86	5.85	3.98	6.05	4.10	6.25	4.23
25.....	5.66	3.90	5.87	4.02	6.08	4.14	6.28	4.26	6.48	4.39
Barley \$30.....										
Millrun \$20.....	6.13	4.23	6.34	4.35	6.55	4.47	6.75	4.59	6.95	4.72
25.....	6.36	4.39	6.57	4.51	6.78	4.63	6.98	4.75	7.18	4.88
30.....	6.59	4.55	6.80	4.67	7.01	4.79	7.21	4.91	7.41	5.04
Barley \$35.....										
Millrun \$25.....	7.05	4.88	7.26	5.00	7.47	5.12	7.67	5.24	7.87	5.37
30.....	7.28	5.04	7.49	5.16	7.70	5.28	7.90	5.40	8.10	5.53
35.....	7.51	5.21	7.72	5.33	7.93	5.45	8.13	5.57	8.33	5.70

of grain fed on forage must be lower than a similar figure for dry lot pigs since no definite value is attached to the forage. It will be found throughout the Tables IV and V that as the concentrates increase in price the margin between prices of grain consumed per unit in dry lot and on forage becomes wider.

PART L—(b) TANKAGE COMPARED WITH FISHMEAL—WHEN MINERALS ARE FED IN SELF-FEEDERS

During the winter of 1921-22, another series of two lots of pigs with 12 head each, was fed to test the comparative feeding value of fishmeal and tankage. The pigs averaged about 50 lbs., being 18 to 20 lbs. lighter than those fed the preceding winter. These two lots

TABLE VI

Tankage Compared with Fishmeal Under Dry Lot Conditions.

	Lot Ia Barley Millrun Tankage	Lot IIa Barley Millrun Fishmeal
No. of pigs.....	12	12
Period of test.....	Dec. 4-Mar. 23	Dec. 4-Mar. 23
Days	110	110
<i>Average Weights and Gains (pounds)</i>		
Average initial wt.....	50.240	51.193
Average final wt.....	166.889	169.278
Total gain	116.649	118.085
Average daily gain.....	1.060	1.074
<i>Pounds Feed Per Cwt. Gain</i>		
Barley	287.07	289.11
Millrun	96.13	96.09
Tankage	53.77	
Fishmeal		45.80
Linseed meal		
Mineral mixture	1.89	1.09
Total	438.86	432.09
<i>Average Daily Ration (pounds)</i>		
Barley	3.043	3.105
Millrun	1.019	1.032
Tankage	.570	
Fishmeal		.492
Mineral mixture	.020	.117
Total	4.652	4.746

Ia and IIa, were self-fed a mineral mixture consisting of 5 parts steamed bone meal, 4 parts air-slacked lime, and 1 part common salt. The pigs were not forced along as much as those of the preceding winter, making average daily gains for the 110-day period of about one pound in both lots. The summary of the test in Table VI, shows no difference in the feeding value of tankage and fishmeal.

It is interesting to note that the pigs consumed from 1 to 2 lbs. of mineral mixture per hundredweight body gain, or, about 2.5-4.5% of the total feed consumed. The pigs in this test were better grown out than those of the preceding year when no mineral mixture was fed and where the pigs were forced along more rapidly. The results of the winter feeding for 1921-22 are in full agreement with the same test carried on during the winter of 1920-21. The mineral mixture did not affect the feed required to make 100 lbs. gain. With mixtures of barley, millrun, and high ash containing feeds like tankage and fishmeal the feeding of mineral mixtures, although undoubtedly of considerable benefit, does not produce as pronounced and as visible benefits as when fed with corn.

PART II.—COCOANUT MEAL COMPARED WITH TANKAGE AND MILLRUN

The cocoanut meal marketed in the Northwest comes largely from the Philippine and Hawaiian Islands. Considerable quantities of this meal are also manufactured from cocoanuts grown on large plantations in India, East Indies, Ceylon, and other tropical countries where they are grown for their content of vegetable oils.

After the nuts are husked they are split into halves and dried in the hot sun. As the meat shrinks, it parts from the outer shell. The air-dried meat is called copra and contains 36% to 54% oil. This oil is expressed in the presence of steam and the cake is left as a by-product which is ground and furnishes the cocoanut meal used for feeding purposes. When in a sound condition, it is red to brown in color, has the characteristic cocoanut odor, is sweet, and well-liked by all farm animals. In hot weather it has a tendency to turn rancid.

The cocoanut meal used in these tests contained 21.5% protein and 8% moisture.

The purpose of this experiment was to secure some information concerning the best method of using cocoanut meal for swine feeding. Whether it is advisable to replace fishmeal or tankage with cocoanut meal, or use it to replace millrun were some questions considered.

Three lots of pigs were fed. One lot received barley, millrun and fishmeal; another was fed a three to one mixture, by weight, of barley and millrun, with enough cocoanut meal to balance the ration.

Since the cocoanut meal contains approximately 22% protein, a larger quantity is necessary to balance the grain mixture than when feeds containing higher percentages of protein are used.

The barley, millrun, tankage and fishmeal were the same as those described under Part I.

In Lot VII, the pigs were much lighter and in consequence the feed consumption less than in the other two lots.

The ration fed to pigs in Lot VII during the winter of 1919-20, contained almost as much cocoanut meal as of barley and tankage combined. It was necessary to feed cocoanut meal in large quantities to furnish enough protein to balance the ration. Such a large proportion of cocoanut meal in the ration of young pigs rendered the feed extremely bulky and unsatisfactory results were obtained. For this reason, the following year cocoanut meal was substituted for millrun rather than for the protein supplements.

It is necessary to compare Lot VIII with Lot IX, receiving fishmeal instead of tankage, because the two lots contained pigs of more similar initial and final weights. The check lot receiving tankage, originally planned for this comparison with the cocoanut meal lot was discontinued because of sickness of some of the pigs before they attained a comparable final weight. In order to present the relation of cocoanut meal and millrun as a hog feed, Lots VIII and IX are compared. The pigs in these two lots were of almost equal weights and the difference in the feeding value of fishmeal and tankage is too slight to be of any practical consequence. Table VII summarizes the work done with cocoanut meal.

The average daily gain of pigs on full feed in Lot VII (see Table VI) is only one-half pound per day and such gains point to the inadvisability of using cocoanut meal to replace feeds like tankage and fishmeal in rations of young pigs. The grain required to make 100 lbs. body gain was 440.1 lbs., which was rather high in comparison to that consumed by pigs in Lot VIII when it is considered that the pigs in Lot VIII finished at a weight of about 172 lbs. as compared to 76 lbs. of those in Lot VII. Light pigs fed rations balanced with tankage may be expected to require much less grain to make such a gain. Pigs in Lot XII (see Table XIII, page 27), started at about the same weight. They were fed in dry lot a ration of barley, millrun and tankage. At the end of thirty days they weighed 108.43 lbs. and required only 381.2 lbs. of concentrates per 100 lbs. of body gain.

An average daily gain per head of 1.429 lbs. for Lot VIII, and 1.440 lbs. for Lot IX was made during a period of 74 days, showing the possibility of feeding cocoanut meal in place of millrun, especially when cocoanut meal is much cheaper than millrun. It required 417.63 lbs. of barley, cocoanut meal, tankage mixture to produce 100

TABLE VII.

Results of Cocoanut Meal Tests Compared with Those For Fishmeal and Tankage.

	Lot VII Dry Lot Barley Millrun Cocoanut Meal	Lot VIII Dry Lot Barley Cocoanut Meal Tankage	Lot IX Dry Lot Barley Millrun Fishmeal
Year	1919-20	1921	1921
Time	Dec. 24-Feb. 21	Jan. 18-Apr. 1	Jan. 18-Apr. 1
Days	60	74	74
No. of pigs per lot.....	6	14	15
<i>Average Weights and Gains (pounds)</i>			
Average initial wt.....	45.50	66.62	68.62
Average final wt.....	75.80	172.33	175.17
Average gain per head.....	30.80	105.71	106.55
Average daily gain.....	.505	1.429	1.440
<i>Average Daily Ration Per Head (pounds)</i>			
Barley	.888	4.084	4.369
Cocoanut meal	1.040	1.361	.....
Millrun	.295	.....	1.455
Tankage .....	.....	.523	.....
Fishmeal .....	.....	.....	.557
Total	2.223	5.968	6.381
<i>Pounds of Feed Per 100 Lbs. of Gain</i>			
Barley	175.8	285.80	303.40
Cocoanut meal	205.9	95.24	.....
Millrun	58.4	.....	101.04
Tankage .....	.....	36.59	.....
Fishmeal .....	.....	.....	38.68
Total	440.1	417.63	443.12

lbs. body gain, while pigs fed barley, millrun and fishmeal required 443.12 lbs. grain to make a similar gain.

The pigs in these two lots were put on test at about the same weight, and finished the test at about the same weight, no marked differences in condition being noticeable.

A comparison of the various constituents necessary to produce 100 lbs. body gain, gives directly the replacement value of cocoanut meal in terms of barley, millrun and fishmeal. It shows that 95.24 lbs. of cocoanut meal has the replacing value of 16.31 lbs. barley, plus 100.70 lbs. millrun plus 2.2 lbs. fishmeal. In this particular trial the cocoanut meal was more valuable than millrun.

Table VIII shows at a glance the approximate cost of 100 lbs. body gain based on the feed requirements of Lot VIII.

TABLE VIII*

Cost of Concentrates Per 100 Lbs. of Body Gain For Pigs Between Weights of 65-150 Lbs. with Varying Feed Prices.

		Price of Tankage Per Ton				
		Lot I \$50.00	Lot II \$60.00	Lot III \$70.00	Lot IV \$80.00	Lot V \$90.00
Barley	\$20.....					
Cocoanut Meal	\$15.....	\$4.48	\$4.66	\$4.84	\$5.02	\$5.20
	20.....	4.72	4.90	5.08	5.26	5.44
	25.....	4.96	5.14	5.32	5.50	5.68
Barley	\$30.....					
Cocoanut Meal	\$20.....	6.15	6.33	6.51	6.69	6.87
	25.....	6.39	6.57	6.75	6.93	7.11
	30.....	6.63	6.81	6.99	7.17	7.35
Barley	\$35.....					
Cocoanut Meal	\$25.....	7.10	7.28	7.46	7.64	7.82
	30.....	7.34	7.52	7.70	7.88	8.06
	35.....	7.58	7.76	7.94	8.12	8.30
Barley	\$40.....					
Cocoanut Meal	\$30.....	8.06	8.24	8.42	8.60	8.78
	35.....	8.30	8.48	8.66	8.84	9.02
	40.....	8.53	8.71	8.89	9.07	9.25

*Based on requirement of 285.90 lbs. barley, 95.24 lbs. cocoanut meal, and 36.31 lbs. tankage per 100 lbs. body gain.

PART III.—LINSEED MEAL AS A PROTEIN SUPPLEMENT IN HOG RATIONS WHEN FED SINGLY AND IN MIXTURES WITH TANKAGE AND WITH FISHMEAL

New process linseed meal is the ground product obtained from seed which has been screened and cleaned of weed seeds, and after extraction of part of the oil by crushing, heating and the use of solvents. Old process linseed meal is the product obtained after extraction of part of the oil by crushing, cooking and hydraulic pressure. The new process linseed meal used during these tests contained 31.15% digestible crude protein. The digestible nutrients of the feeds fed in this series follow:

	Per Cent Crude Protein	Per Cent Total Digestible Nutrients
Barley	5.31	70.60
Millrun	15.64	74.51
Linseed Meal	31.15	71.65
Digester Tankage	36.20	65.80
Fishmeal	41.36	65.80

The above figures were calculated from direct analyses made of the feeds and by use of coefficients of digestibility worked out with pigs for similar feeds and reported in Special Bulletin of the Massachusetts Agricultural Experiment Station for November, 1919.

The work with linseed meal was undertaken to study the effectiveness of a vegetable protein supplement in supporting growth of fattening pigs. A comparison with protein rich feeds of animal origin is also made. Since tankage and fishmeal cost more per ton than linseed oil meal, a study of the entire or partial substitution of the cheaper feed for the more costly ones is of interest. Furthermore, mixtures of equal parts of fishmeal with linseed oil meal, or of tankage with linseed meal, might be expected to contain a protein of better quality than either feed fed alone, one probably correcting the deficiency of the other.

To study the points a series of rations was planned according to the following scheme:

Lot I—3 parts rolled barley, 1 part millrun, tankage to balance ration.

Lot II—3 parts rolled barley, 1 part millrun, fishmeal to balance ration.

Lot III—3 parts rolled barley, 1 part millrun, linseed meal to balance ration.

Lot IV—3 parts rolled barley, 1 part millrun, equal parts tankage and linseed meal to balance ration.

The proportions of feeds fed are given in Table II.

An idea of the comparative feeding value of linseed meal, fishmeal and tankage can be obtained from Table IX. Later another lot was fed a supplement consisting of equal parts of fishmeal and linseed meal.

From the following table it is evident that the fishmeal lot (Lot II) made the highest average daily gain of 1.074 lbs. followed by 1.060 lbs. for those fed tankage. The linseed meal lot made the lowest gain of .922 lbs. The grain required to produce 100 lbs. gain was largest for the pigs fed linseed meal. At the close of the test, the pigs in Lot III were in slightly higher condition than those in Lots I and II and were "chubbier" but not grown out as well.

The results indicate that there is very little difference in the feeding value of 59% protein tankage and 67% protein fishmeal. They are in agreement with the results of the two years immediately preceding where no difference in feeding value of 60% protein tankage and 56% protein fishmeal could be detected in both dry lot and on forage. The vegetable protein supplement did not produce as good gains and as satisfactory growth as the protein rich feeds of animal origin. Results with mixtures of linseed meal with either tankage or fishmeal are included in Table X.

Mixtures of equal parts of linseed meal and tankage and of linseed meal with fishmeal proved to be better supplements than linseed meal alone, but were not as good as either fishmeal or tankage fed singly. The mixture of equal parts of tankage and linseed meal pro-

TABLE IX

Part III—The Value of Linseed Meal as Compared with Tankage and with Fishmeal When Fed to Hogs Under Dry Lot Conditions.

	Lot III Barley Millrun Linseed meal	Lot I Barley Millrun Tankage	Lot II Barley Millrun Fishmeal
No. of pigs.....	12	12	12
Period of test.....	Dec. 4-Mar. 23	Dec. 4-Mar. 23	Dec. 4-Mar. 23
Days	110	110	110
<i>Average Weights and Gains (pounds)</i>			
Average initial wt.....	50.000	50.240	51.193
Average final wt.....	151.403	166.889	169.278
Total gain	101.403	116.649	118.085
Average daily gain.....	.922	1.060	1.074
<i>Pounds Fed Per 100 Lbs. Gain</i>			
Barley	314.75	287.07	289.10
Millrun	105.20	96.13	96.87
Tankage .....	.....	53.77	.....
Fishmeal .....	.....	.....	45.80
Linseed meal	81.45	.....	.....
Mineral mixture	.43	1.88	1.09
Total	501.83	438.85	432.36
<i>Average Daily Ration (pounds)</i>			
Barley	2.902	3.043	3.105
Millrun	.970	1.019	1.035
Tankage .....	.....	.570	.....
Fishmeal .....	.....	.....	.492
Linseed meal	.751	.....	.....
Mineral mixture*	.004	.020	.117
Total	4.627	4.652	4.749

*Mineral mixture consisted of 5 parts bone meal, 4 parts air-slacked lime, and 1 part salt. It was valued at \$20.00 per ton.

duced slightly higher average daily gains than the pigs fed linseed meal as a supplement. Lot V fed a supplement consisting of equal parts of linseed meal and fishmeal made the largest daily gains. The figures for this lot can hardly be compared with those for the other four lots. The pigs in this lot were out of later litters, and were placed on feed a whole month later. Since they were fed 110 days just like the other four lots, they had a month of more favorable weather during the latter part of the test. Their feed consumption was greater and they finished at an average weight of 204.19 lbs., as

TABLE X

A Comparison of Linseed Meal Fed Singly and in Mixtures with Tankage and Fishmeal in Balanced Hog Rations.

	Lot III	Lot IV	Lot V
	Barley Millrun Linseed meal	Barley Millrun Linseed meal Tankage	Barley Millrun Linseed meal Fishmeal
No. of pigs.....	12	11	7
Period of test.....	Dec. 4-Mar. 23	Dec. 4-Mar. 23	Jan. 13-May 2
Days	110	110	110
<i>Average Weights and Gains (pounds)</i>			
Average initial wt.....	50.00	51.319	58.571
Average final wt.....	151.403	158.439	204.190
Total gain	101.403	107.120	145.615
Average daily gain.....	.922	.974	1.324
<i>Pounds Feed Per 100 Lbs. Gain</i>			
Barley	314.75	306.05	337.613
Millrun	105.20	101.54	112.387
Tankage .....	.....	33.78	.....
Fishmeal .....	.....	.....	23.414
Linseed meal	81.45	33.78	23.414
Mineral mixture	.43	1.20	2.266
Total	501.83	476.35	499.094
<i>Average Daily Ration (pounds)</i>			
Barley	2.902	2.981	4.470
Millrun	.970	.989	1.488
Tankage .....	.....	.329	.....
Fishmeal .....	.....	.....	.310
Linseed meal	.751	.329	.310
Mineral mixture	.004	.117	.039
Total	4.627	4.745	6.608

compared to 151.403 lbs. for the linseed meal lot. Owing to their higher condition, a higher grain requirement per unit gain is expected. The mixtures appear to have no distinct advantage. The greater feed consumption by this lot would tend to show that this mixture was highly palatable.

PART IV.—CANE MOLASSES COMPARED WITH BARLEY ON FORAGE AND UNDER DRY LOT CONDITIONS

Hawaiian cane molasses coming into the western parts of Washington can frequently be obtained at a lower price per ton than cereal grains. For this reason the work was outlined so as to obtain directly a comparison of the feeding value of cane molasses and rolled barley for pigs.

Two lots of pigs were fed in dry lot, all receiving barley, millrun and tankage, with the exception that one lot had one-half of its barley replaced by cane molasses. Two other lots received similar feeds while pasturing peas, the rations on forage being about one-half in quantity of those fed in dry lot.

The average daily gains and feed required per unit of gain when initial and final weights of the hogs in various lots are practically identical, form the basis of comparing barley with molasses.

The barley, millrun and tankage are the same in part as those fed to pigs in lots discussed under Parts I and II, and III.

The cane or black strap molasses is a product of sugar refineries and is composed largely of plant juices having a varying sugar content. It is a palatable and appetizing feed, the nutritive value of which depends upon a varying sugar content, which may range from 45% to 60%, depending on thoroughness with which sugar is extracted. It is strictly a sugar feed, supplying only traces of protein and no fat. The moisture variation of molasses fed during this test was small, ranging from 30% to 31%.

Cane molasses may be fed in small quantities as an appetizer, but in the dry-lot tests it replaced one-half of the barley in the proportion of one and one-half parts molasses to one part barley and on pea forage it replaced equal parts by weight of barley.

The pigs in Lot I consumed an average of 5.8 lbs. grain mixture per day. This consisted of about 67½% rolled barley, 22½% millrun, and 10% tankage.

Those in Lot X received the same ration with the exception that about 2.5 lbs. of cane molasses was substituted for 1.6 lbs. rolled barley. This is in about the proportion of 1½ parts molasses for one part rolled barley. Although the pigs in Lot X consumed 6.65 lbs. of feed per day, it included 2½ lbs. of cane molasses containing 31% moisture, so that on the basis of dry matter, the ration of this lot compares much more favorably with that of Lot I than is apparent from Table XI.

The pigs in Lots III and XI, on pea forage, received similar grain rations, except that one-half of the barley in the ration of Lot XI was substituted for an equal weight of cane molasses.

The molasses was fed one part to three parts of water and mixed with grain to form a thick slop. The results of the trials with molasses are presented in Table XI.

In the following table (Table XI) it will be noted that the average initial and final weights of pigs in the four lots permit very accurate comparisons.

Lot I made an average daily gain of 1.314 lbs. for 57 days, consuming 441.33 lbs. feed to make 100 lbs. gain; while Lot X, receiving molasses, averaged 1.116 lbs. daily per head for 74 days and required

TABLE XI
Results of Feeding Tests with Cane Molasses.

	Lot I	Lot X	Lot III	Lot XI
	Dry Lot Barley Millrun Tankage 60% Molasses	Dry Lot Barley Millrun Tankage 60% Molasses	Pea Forage Barley Millrun Tankage 60%	Pea Forage Barley Millrun Tankage 60% Molasses
Year	1921	1921	1920	1920
Date	Jan. 18- Mar. 15	Jan. 18- April 1	July 19- Sept. 30	July 19- Sept. 30
Days	57	74	74	74
No. of pigs per lot....	14	14	17	8
<i>Average Weights and Gains (pounds)</i>				
Average initial wt.....	69.64	65.78	65.49	65.65
Average final wt.....	144.52	148.38	144.32	149.86
Average gain per head	74.88	82.60	78.83	84.21
Average daily gain....	1.314	1.116	1.065	1.138
<i>Pounds Feed Per 100 Lbs. Gain</i>				
Barley	298.02	207.07	193.51	84.18
Millrun	99.32	116.48	64.41	53.51
Tankage	43.99	44.71	27.32	23.11
Molasses .....	.....	227.78	.....	89.63
Total	441.33	*596.04	285.24	250.43
<i>Average Daily Ration Per Head (pounds)</i>				
Barley	3.916	2.311	2.061	.958
Millrun	1.305	1.300	.686	.609
Tankage	.578	.499	.291	.263
Molasses .....	.....	2.542	.....	1.020
Total	5.799	6.652	3.038	2.850

*This figure includes 227.78 lbs. of cane molasses containing 31% of moisture.

596.04 lbs. feed per 100 lbs. body gain. It took the molasses-fed lot 17 more days to reach a weight similar to those of the hogs in Lot I.

Under the condition of this trial 91.10 lbs. of barley were equivalent in feeding value to 17.11 lbs. millrun plus .73 lbs. tankage plus 227.79 lbs. cane molasses.

The work with molasses on forage, where molasses was substituted for an equal weight of barley, gave more favorable results. The pigs in Lot III made an average daily gain for 74 days of 1.065 lbs. with a grain requirement of 285.24 lbs. per 100 lbs. body gain. The pigs receiving molasses in Lot XI made an average daily gain per head of 1.138 lbs. for 74 days consuming 250.43 lbs. concentrates, in-

TABLE XII
Cost of Feed Per 100 Lbs. Gain at Varying Feed Prices.

Cost Per Ton	Lot I Tankage \$60		Lot II Tankage \$70		Lot III Tankage \$80		Lot IV Tankage \$90		Lot V Tankage \$100	
	Dry Lot	Forage	Dry Lot	Forage	Dry Lot	Forage	Dry Lot	Forage	Dry Lot	Forage
Barley \$20...	\$5.99	\$2.60	\$6.21	\$2.72	\$6.44	\$2.83	\$6.66	\$2.95	\$6.89	\$3.07
Millrun \$15	6.56	2.83	6.78	2.95	7.01	3.06	7.23	3.18	7.46	3.30
Molasses 20	7.13	3.05	7.35	3.17	7.58	3.28	7.80	3.40	8.03	3.52
Barley \$25										
Millrun \$20	7.37	3.18	7.59	3.30	7.83	3.41	8.04	3.52	8.27	3.65
Molasses 20	7.94	3.40	8.16	3.52	8.39	3.62	8.61	3.75	8.84	3.87
Barley \$30	8.51	3.62	8.73	3.74	8.96	3.85	9.17	3.97	9.41	4.09
Barley \$30										
Millrun \$25	8.75	3.74	8.97	3.86	9.20	3.97	9.42	4.09	9.65	4.21
Molasses 30	9.32	3.96	9.54	4.08	9.77	4.19	9.99	4.31	10.22	4.43
Barley \$35	9.89	4.19	10.11	4.31	10.34	4.42	10.56	4.54	10.79	4.66
Barley \$30										
Millrun \$20	9.04	3.87	9.26	3.99	9.49	4.10	9.71	4.22	9.94	4.34
Molasses 25	9.61	4.09	9.83	4.21	10.06	4.32	10.28	4.44	10.51	4.56
Barley \$40	10.18	4.32	10.40	4.44	10.63	4.55	10.85	4.67	11.08	4.79
Barley \$35										
Millrun \$30	11.51	4.88	11.73	5.00	11.96	5.11	12.28	5.23	12.41	5.35
Molasses 40	12.08	5.10	12.30	5.22	12.53	5.33	12.75	5.45	12.98	5.57
Barley \$45	12.64	5.33	12.86	5.45	13.09	5.56	13.32	5.68	13.54	5.80
Barley \$40										
Millrun \$40	11.80	5.01	12.02	5.13	12.25	5.24	12.47	5.36	12.70	5.48
Molasses 40	12.37	5.23	12.59	5.35	12.82	5.46	13.04	5.58	13.27	5.70
Barley \$45	12.93	5.46	13.15	5.58	13.39	5.69	13.61	5.81	13.83	5.93

cluding molasses, per 100 lbs. body gain. The molasses-fed pigs required 34.67 lbs. less concentrates per 100 lbs. gain.

In this test 109.27 lbs. barley, 10.88 lbs. millrun, 4.18 lbs. tankage plus pea forage, had the feeding value of 89.66 lbs. molasses plus pea forage.

The cost of producing 100 lbs. of pork with the feeds at different prices, was computed on the basis of the conditions of the foregoing experiment. These figures are included in Table XII.

PART V.—PRODUCTION OF PORK ON FORAGE

Hogs fed on forage compared with those fed in dry lot are usually healthier and more vigorous. They have the advantage of cleaner surroundings, more exercise and a feed of a laxative nature, which minimize the chance of digestive disorders. The labor saved in harvesting the crop and caring for the manure as well as the lower grain requirement per pound of pork produced, are points in favor of this system of raising spring farrowed pigs.

Successful forage crops for hogs should be well adapted to the climatic and soil condition, so as to furnish forage for a long growing season and to produce sufficient feed per acre to compete with other crops grown under similar conditions. They should be palatable and fairly high in protein. Legume crops have this advantage.

At the present time the two most common forage crops used for hogs in Eastern Washington are alfalfa and peas.* Vetch is also grown to a limited extent for this purpose. The work here reported is confined to experiments with the first two crops.

The work provided for two lots of pigs on pea forage to receive the same grain rations with the exceptions that one lot was to receive tankage, the other lot fishmeal. The two lots received similar rations. For each forage lot there was to be a check lot of comparable pigs fed in dry lot, so that returns per acre of forage could be determined directly.

The work was planned to have the initial and final weights of lots of pigs in each set of comparisons as nearly alike as was practical, permitting the length of the test to vary, if necessary, to attain this end. The grain required to produce 100 lbs. of gain by the check lot was to be used in determining what part of the total gain of pigs on forage receiving grain was due to grain and what part was due to forage.

The feeds used in dry lot and on forage have been already discussed under a similar heading in previous parts.

Table XIII is a summary of the forage and dry-lot feeding tests which form the basis of evaluating an acre of each forage tested.

*Although the mature seed is the main factor in hogging off of peas, enough of the stems and leaves are consumed by the pigs to warrant classifying this crop as a forage crop.

The profit per acre of forage, when grain is fed to hogs on pasture, can be calculated by first figuring the grain requirement for the production of 100 lbs. of pork for the pigs fed in dry lot. The total grain fed the lot of pigs on forage is divided by this figure. The quotient is the estimated amount of pork that the total grain fed on forage would have yielded had it been fed in dry lot. By subtracting this quotient from the actual amount of pork produced per acre the result represents the amount of pork to be accredited to the forage.

Another method of evaluating the forage is by calculating the grain required to produce 100 lbs. of gain on pigs in dry-lot tests as compared with the grain requirement for similar gains with pigs on forage lots. The number representing the total pounds of pork produced per acre of forage is multiplied by the amount of grain consumed per pound of gain by the pigs in dry lot. The product is the estimated grain equivalent necessary to produce that quantity of pork in dry lot. Subtracting from the grain equivalent the grain consumed by the pigs running on one acre of forage the result represents the grain saved by that area of forage.

In Table XIII are tabulated the results with eight lots of pigs, four lots being fed in dry lot and the same number fed on forage.

Lots I and II, III and IV, XII and V, XIII and VI form the basis of evaluating the two forages tested.

Lot III, on pea forage, receiving a balanced grain mixture of barley, millrun and tankage, required 156.1 lbs. less grain to make 100 lbs. of gain than the dry-lot pigs in Lot I. This quantity of grain included 104.63 lbs. barley, 34.95 lbs. millrun and 16.67 lbs. of tankage.

There were eight pigs per acre, and the average total gain per pig for the experimental period was 78.83 lbs. The forage and grain produced a total of 630.64 lbs. of pork. The grain required in dry lot (see Lot I) to produce 100 lbs. of pork was 441.3 lbs. To produce 630 lbs. pork under those conditions would require 2781.2 lbs. of grain mixture. The grain fed besides the forage consumed in Lot III was 285.2 lbs. (see Table XIII, Lot III). To produce 630 lbs. of pork on forage would have required 6.3 times the above quantity or 1796.8 lbs. grain.

The saving of grain due to an acre of pea forage estimated to yield 17 bushels of grain per acre (1020 lbs.) was 659.2 lbs. barley, 220.1 millrun and 105.0 lbs. tankage, a total of 984.3 lbs., which would produce 223 lbs. of pork in dry lot. It is of interest to note in the comparisons of pigs that the average initial and final weights for the forage lots and dry lots are almost identical. This eliminates discrepancies due to differences of weight.

Lot II and IV when compared in a similar manner as Lots I and II may be expected to show only slight differences because fishmeal

TABLE XIII
Results of Dry-Lot Tests Compared with Similar Test on Forage.

	Lot I Dry Lot	Lot III Pea Forage	Lot II Dry Lot	Lot IV Pea Forage	Lot XII Dry Lot	Lot V Alfalfa Pasture	Lot XIII Dry Lot	Lot VI Alfalfa Pasture
No. of pigs	14	17	14	18	14	7	14	7
No. of pigs per acre	....	8	....	6	....	11	....	11
Date*	Jan. 18- Mar. 15	July 19- Sept. 30	Jan. 18- Mar. 15	July 19- Sept. 30	Jan. 18- Feb. 30	Aug. 11- Oct. 14	Jan. 18- Feb. 16	Aug. 11- Oct. 14
Days	57	74	57	74	30	65	30	65
	Barley Millrun Tankage 60%	Barley Millrun Tankage 60%	Barley Millrun Fishmeal 56%	Barley Millrun Fishmeal 56%	Barley Millrun Tankage 60%	Barley Millrun Tankage 60%	Barley Millrun Fishmeal 56%	Barley Millrun Fishmeal 56%
Average Weights and Gains (pounds)								
Av. initial wt.	69.641	65.490	68.615	66.40	69.710	40.800	68.620	40.800
Av. final wt.	144.521	144.320	148.473	146.22	108.430	92.900	107.000	93.400
Av. total wt.	74.88	78.83	79.86	79.82	38.72	52.10	38.38	52.60
Av. daily gain.	1.314	1.065	1.401	1.079	1.391	.302	1.28	.309
Pounds Feed Per 100 Lbs. Gain								
Barley	298.0	193.5	278.4	198.6	253.4	208.2	255.1	208.9
Millrun	99.3	64.4	92.8	65.5	84.5	69.8	86.0	69.2
Tankage	44.0	27.3	....	....	43.3	42.4	....	....
Fishmeal	....	....	41.0	24.6	....	....	43.5	39.5
Total	441.3	285.2	412.2	286.7	381.2	320.4	383.6	317.6

Average Daily Ration Per Head (pounds)

Barley	3.918	2.061	3.901	2.122	3.272	1.67	3.265	1.69
Millrun	1.305	.886	1.300	.707	1.091	.56	1.088	.56
Tankage	.578	.291	.575	.266	0.559	.34	.557	.32
Fishmeal								
Total	6.799	3.038	5.776	3.095	4.922	2.57	4.910	2.57
Pounds of pork per acre due to forage		†222.9		‡145.8		§81.7		§80.7

*Forage tests were conducted in 1920, and dry lot tests during the winter of 1920-21.

†Average yield per acre 17.0 bushels.

‡Average yield per acre 15.5. † and ‡ vary because there were 8 pigs per acre in Lot III.

§First cutting taken off as hay crop.

was fed instead of tankage—but the major cause of difference would be due to the fact that in Lot IV there were six pigs per acre of peas as compared to eight pigs per acre of peas in Lot III.

Such a comparison shows that an acre of peas yielding 15.5 bushels per acre (930 lbs. of peas) carrying six pigs, effected a saving of 391.9 lbs. barley, 230.8 lbs. millrun, 78.4 lbs. fishmeal, a total of 601.1 lbs.

This quantity of grain, basing the comparison on Lot II would produce 145.81 lbs. pork in dry lot. It is seen that returns per acre are not as good with six pigs as with eight, and it shows that six pigs per acre are not sufficient for maximum returns. In subsequent tests the carrying capacity per acre of peas will be increased. By comparing Lots XII and V, and XIII with VI, the returns per acre of alfalfa forage can be determined.

The first comparison shows a saving of 311.7 lbs. of balanced grain mixture per acre of forage with eleven pigs to the acre, the second comparison showing a saving of 309.6 lbs. balanced grain mixture. These quantities fed in dry lot to pigs of similar weights would have produced 81.7 lbs. of pork and 80.1 lbs. of pork, respectively.

The alfalfa was pastured 66 days, from August 11 to October 15, inclusive, after the first crop of hay was removed.

The pea forage reduced the grain necessary to make 100 lbs. gain by 47.6%, and alfalfa forage effected a saving of 47.8% for an identical gain.

For the cost of 100 lbs. body gain of hogs on pea forage as compared to costs of similar gains in dry lot with varying feed prices, see Tables IV, V and XII.

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STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISION OF ANIMAL HUSBANDRY

LAMB FEEDING EXPERIMENTS
AT THE IRRIGATION BRANCH STATION

— By —

H. HACKEDORN, R. P. BEAN and J. SOTOLA

BULLETIN NO. 170

August 1922

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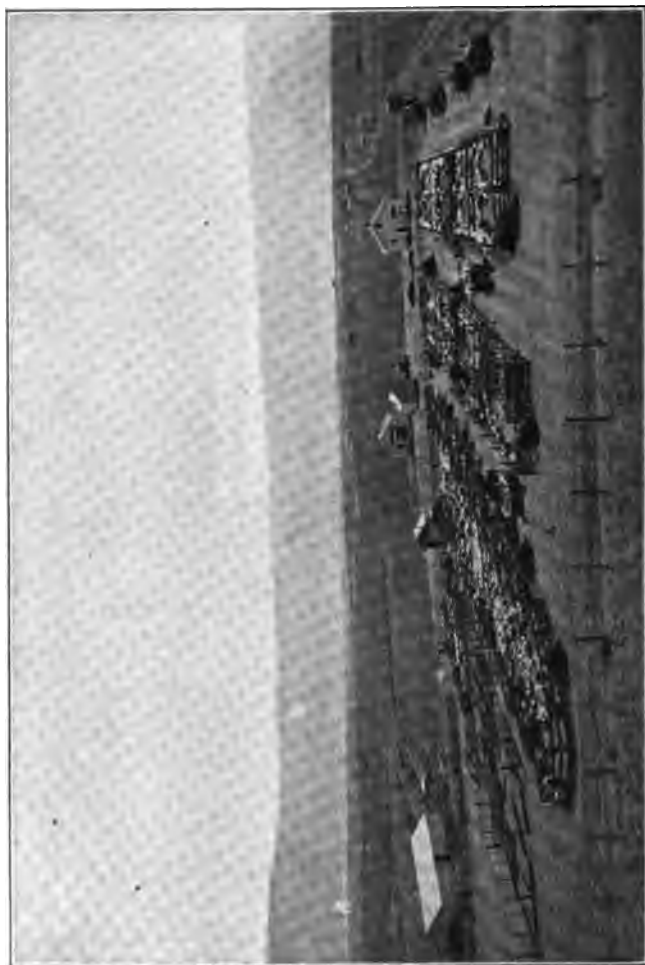
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*In co-operation with the United States Department of Agriculture.

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**GENERAL VIEW OF FEEDING LOTS AT THE IRRIGATION BRANCH STATION
PROSSER, WASH.**

LAMB FEEDING EXPERIMENTS

AT THE IRRIGATION BRANCH STATION

By

H. HACKEDORN, R. P. BEAN and J. SOTOLA

INTRODUCTION

It is recognized that most lamb feeders are desirous of knowing more about the comparative feeding values of first, second and third cuttings of alfalfa hay. Also an increasing interest is shown in sweet clover hay in regions where land is not suited to alfalfa. The best proportion of grain to roughage to be fed in rations of fattening lambs for most economical returns is also of general interest. Likewise the advisability of producing corn silage for fattening lambs, when good quality hay is available is more or less questioned. The practice of feeding cottonseed meal in rations for fattening lambs is dependent chiefly upon the extent and cost of grains produced and upon the market quality secured in the animals above those on similar rations where no cottonseed meal is fed. The advisability of feeding cottonseed meal is also affected by the quality of roughage fed. The feeders in the sugar beet sections and adjacent areas can profit by a study of the method of feeding beet molasses in direct comparison with known concentrates so that there may be some reliable basis for evaluating this feed.

In this publication there are presented and discussed the data obtained during the winter of 1921-22 from experiments conducted at the Washington Irrigation Branch Station at Prosser for the purpose of obtaining definite information of immediate value, having a direct bearing on the preceding questions and topics. The material is divided and discussed under four general subheads for the purpose of comparing the following:

Part I—(A) First, second and third cuttings of alfalfa hay.

(B) First cutting sweet clover hay with first cutting alfalfa hay.

Part II—Light and heavy grain rations.

Part III—Silage, hay rations with straight hay rations.

Part IV—Beet molasses with corn when it replaces one-third of the corn.

PLAN AND DESCRIPTION OF EXPERIMENT

THE PLAN:

In each sub-group of the experiment the lambs were divided into lots of 50 head each. Lots I and VII being duplicates, are averaged together as Lot I. This one lot of 100 lambs fed first cutting alfalfa

hay, is compared with lots of 50 lambs fed 2nd and 3rd cutting of alfalfa hay and with another lot of 50 lambs fed first cutting sweet clover hay.

An outline of the rations fed follows:

PART I

(A) To compare first, second and third cuttings of alfalfa hay.

Lot I— $\frac{3}{4}$ lbs. corn, first cutting alfalfa hay

Lot II— $\frac{3}{4}$ lbs. corn, second cutting alfalfa hay

Lot III— $\frac{3}{4}$ lbs. corn, third cutting alfalfa hay

(B) To compare sweet clover hay with first cutting alfalfa hay

Lot I— $\frac{3}{4}$ lbs. corn, first cutting alfalfa hay

Lot IV— $\frac{3}{4}$ lbs. corn, first cutting sweet clover hay

PART II

To compare light and heavy grain rations

Lot V— $1\frac{1}{2}$ lbs. corn, alfalfa hay (first cutting)

Lot VI—1 lbs. corn, alfalfa hay (first cutting)

Lot I— $\frac{3}{4}$ lbs. corn, alfalfa hay (first cutting)

Lot VIII— $\frac{1}{2}$ lbs. corn, alfalfa hay (first cutting)

Lot XIII— $\frac{3}{4}$ lbs. corn, alfalfa hay (first cutting)

PART III

To study the value of corn silage—hay rations in comparison to straight hay rations.

(A) Lot V— $1\frac{1}{2}$ lbs. corn, alfalfa hay (first cutting)

Lot IX— $1\frac{1}{2}$ lbs. corn, $1\frac{1}{2}$ lbs. corn silage, alfalfa hay, (first cutting)

Lot XI— $1\frac{1}{2}$ lbs. mixture (7 parts corn, 1 part cottonseed meal)
 $1\frac{1}{2}$ lbs. corn silage and alfalfa hay (first cutting)

(B) Lot I— $\frac{3}{4}$ lbs. corn, first cutting alfalfa hay

Lot X— $\frac{3}{4}$ lbs. corn, $1\frac{1}{2}$ lbs. corn silage and first cutting alfalfa hay

Lot XII— $\frac{3}{4}$ lbs. mixture (7 parts corn, 1 part cottonseed meal),
 $1\frac{1}{2}$ lbs. corn silage and alfalfa hay

PART IV

To compare beet molasses with corn when it replaces one-third of the concentrates.

Lot V— $1\frac{1}{2}$ lbs. corn, alfalfa hay (first cutting)

Lot XIV—1 lb. corn, $\frac{1}{2}$ lb. beet molasses, alfalfa hay (first cutting)

THE LAMBS

A band of 1675 "cut-back" lambs was bought from several sheepmen near Yakima. From this number 700 head were selected for uniformity and condition and were put into the experimental lots. Most of them were by Hampshire rams and from "half-blood" ewes. At the beginning of the test the lambs averaged 61 to 66 lbs. in weight. Most of them were fairly well-grown out, of good quality, and rather thin. They had received no concentrates previous to the feeding test.

TREATMENT OF LAMBS UP TO THE BEGINNING OF EXPERIMENT

The lambs had access to alfalfa pasture at the Experiment Station farm near Prosser, from October 27th, 1921, until November 18, 1921, when the first snow storm necessitated full feeding of hay for several days. After the snow thawed and the ground dried, the lambs were fed $\frac{1}{2}$ lb. of alfalfa hay per head daily in addition to frosted alfalfa pasture.

After the early morning fill the lambs would lie down and rest. Towards the middle of the day whole hay was fed, thinly scattered over a field of corn stubble. During this period all the weedy hay, mixtures of rye and sweet clover hay and dried Russian thistles were fed and disposed of. At this time the lambs had free access to salt. The pasture season ended December 22nd with a fairly heavy snow for this section. The total loss of lambs up to the beginning of the experiment was 25 head.

FEEDS FED DURING TEST

The corn fed in this experiment was shipped from the Middle West, grading as No. 3 yellow. All of the alfalfa hay fed was produced on the Station Farm, being well-cured and leafy. Of the three cuttings the second was the coarsest, the third cutting being the finest. The second cutting was not as coarse as usual since it was not permitted to mature as much as the first. All the lambs fed alfalfa received first cutting hay with the exception of Lots II and III. The three cuttings of hay yielded an average of $4\frac{1}{2}$ tons to the acre.

The sweet clover hay was rather coarse, but otherwise of good quality. It was cut when 24-30 inches high. It was raked and shocked as soon as wilted to cause it to cure slowly in order to prevent undue loss of leaves.

The corn silage was produced from frosted corn which had hardly attained the stiff-dough state at the time of ensiling. It was grown on new land, which was not previously in alfalfa. A field of 14 acres yielded approximately 100 tons of silage. The top layers were rather dry but later in the feeding period the quality of silage improved.

The beet molasses was purchased from the Utah-Idaho Beet Sugar Co., of Toppenish, Wash. Because of its bitter taste and comparatively large content of free potassium and magnesium salts, it exerts a strong purgative action on animals when fed in large quantities. Owing to the slump in sugar prices it has been generally admitted that molasses is of better quality than in previous years, because of a higher sugar content. However, it is the policy of the manufacturer to extract all of the sugar possible from the beet juices each year, irrespective of sugar prices, and under such conditions there can be but little variation in the feeding value of the molasses. The quality

of the beets some years makes it difficult to extract the sugar, but at best this would cause only a small variation.

ANALYSES OF FEEDS

Analyses of the feeding stuffs used throughout the test are included in Table I. The cottonseed meal contained only 34.6 per cent crude protein, which is 3 per cent below the limit for the good grade of this concentrate. According to the classification agreed upon by feed control officials such a protein content puts this feed into the class of "cottonseed feeds" rather than cottonseed meals.

The figures for the three cuttings (Table I) of alfalfa show very little difference between them. Since the water content of the hay from all three cuttings varies but little a direct comparison of percentages of other constituents is possible. Such a comparison shows the second cutting hay to rank highest with a protein content of 13.75 per cent, and the first and third cutting containing 13.44 per cent and 12.97 per cent protein respectively. The same order obtains for the fat content. The third cutting hay is highest in crude fibre but the difference is not large since the maximum variation for all cuttings does not exceed much over 3 per cent.

The sweet clover compares favorably with the alfalfa hay. Even though apparently stemmier and higher in fibre content, the analysis shows no such difference. Such fibre is determined by treating feed samples each with 1.25 per cent sulfuric acid and 1.25 per cent alkali for $\frac{1}{2}$ hour periods, the immature plant tissue of the sweet clover which was cut for hay at an early stage is rendered soluble by such treatment and appears as a part of the nitrogen free extract in the table. If the sweet clover had been permitted to mature more, it no doubt would have had a much higher crude fibre content both due to a greater hardening of the cellulose and an increase in proportion of cell enclosures as well as to a loss of leaves. The table follows:

TABLE I
CHEMICAL COMPOSITION OF FEEDS FED DURING TEST

	Dry Matter	Crude Protein N x 6.25	Crude Fat	Crude Fibre	N. F. Ext.	Ash
Corn	91.11	8.75	4.23	2.04	75.96	13
Cottonseed Meal	90.87	34.60	7.93	10.18	31.88	6.28
Alfalfa hay—						
1st cutting	93.37	13.44	1.85	29.40	38.21	10.47
2nd cutting	93.57	13.75	2.24	31.48	37.37	8.73
3rd cutting	93.31	12.97	1.60	32.60	36.94	9.20
Sweet Clover	93.43	12.50	1.74	28.70	40.39	10.10
Molasses	79.80	8.50	.....	.....	64.65	6.65
Corn Silage	39.70	.62	.81	13.40	20.80	4.07

The coefficients of digestibility for first and third cutting alfalfa hay as well for sweet clover show very little variation for the same nutrient. The figures for second cutting alfalfa hay are uniformly higher.

TABLE II
(Experiments with Ruminants)
COEFFICIENTS OF DIGESTIBILITY*
(Taken from Mass. Special Bul., Nov., 1919.)

	Crude Protein Nx 6.25	Crude Fat	Crude Fibre	N.F. Ext.
Corn	67	90	44	92
Cottonseed Meal	84	95	32	77
Alfalfa Hay—				
1st cutting	70	38	41	73
2nd cutting	77	42	46	74
3rd cutting	71	30	42	68
Sweet Clover	75	31	34	72
Molasses†	62	---	---	91
Corn Silage	51	82	65	71

Table III contains the percentages of digestible nutrients in the various feeding stuffs. These are calculated by multiplying the percentage of any nutrient in a certain feeding stuff by its corresponding coefficient of digestibility and dividing the result by 100. The resulting table is used as the basis for computing the digestible protein, and total digestible nutrient contents of daily rations fed throughout the test.

†From Henry and Morrison "Feeds and Feeding," 17th ed., pp. 468.

*Digestibility of feeds is generally measured by the amount of nutrients of those feeds retained by animals. If 6 lbs. of protein are fed and 2 lbs. appear in the feces, it is evident that only 4 lbs. were retained. The digestibility of protein in this case is $\frac{2}{3}$ or 66- $\frac{2}{3}$ per cent. Digestibility is expressed by a term known as the "Coefficient of Digestibility." Instead of the above protein being 66- $\frac{2}{3}$ per cent. digestible, it is customary to say that its coefficient of digestibility is 66- $\frac{2}{3}$.

TABLE III
DIGESTIBLE NUTRIENTS PER 100 LBS. OF FEEDS FED
DURING TEST

	Crude Protein	Crude Fat	Crude Fibre	Nitrogen Free Ext.	*T. D. Nutrients	†Nutritive Ratio 1:
Corn	5.86	3.81	.90	69.88	85.21	13.5
Cottonseed Meal	29.06	7.53	3.26	24.55	73.81	1.5
Alfalfa Hay—						
1st cutting	9.41	.70	12.05	27.89	50.93	4.4
2nd cutting	10.59	.94	14.48	27.65	54.84	4.2
3rd cutting	9.21	.48	13.69	25.12	49.10	4.3
Sweet Clover Hay.....	9.38	.48	9.76	29.08	49.43	4.3
Molasses	5.27	.....	.....	58.83	64.10	11.1
Corn Silage.....	.32	.66	8.71	14.77	25.30	77.9

EQUIPMENT

The lambs were fed in open feed lots located on a sandy south-eastern slope. The lots were 10 feet wide and 56 feet long, just accommodating 50 lambs, and the fencing consisted of wooden panels having 8 to 9-inch neck spaces at the bottom, these spaces opening into troughs having a 12-inch base and a top 17½ inches wide. The 12-inch trough bottom was one inch wider than necessary and interfered slightly with the feeding of grain during the early part of the feeding period. However, during the latter part of the feeding period as the lambs increased in size, this difficulty was overcome.

The panels were built of rough lumber, and of about the type that most feeders use for the erection of inexpensive feed lots to carry on their feeding operations. These panels were stacked in the spring and the feed lot area planted to corn.

Method of Feeding

The daily ration was fed in two equal portions, one at 7:00 A. M. and the other at 4:00 P. M. All silage was fed with the morning feed immediately after being taken out of the silo. Both hay and grain were conveniently fed from the troughs. The troughs were swept carefully before each feeding and the refuse was piled up for future weighing. During the early part of the test the feeding of grain began at 3:30 P. M. so as to give the lambs time to clean up the hay before dark. Parts of the refuse hay of the evening feed were consumed early in the morning before the grain feeding began. The

*Total Digestible Nutrients or the sum of protein, fibre, nitrogen free extract plus 2.25 times crude fat.

†Nutritive Ratio is the ratio of digestible protein to the digestible carbohydrates plus 2.25 times digestible crude fat.

grain was fed first followed by the hay. It was found advisable to turn and stir up the hay in the troughs, so as to bring the leafy portions directly before the lambs. This point has greater significance when the hay is fed on the ground than when it is fed in troughs. The lambs in Lot XIV received molasses twice daily on top of the corn feed. This sweet feed was warmed and diluted with about 3 volumes of water to make it flow readily. Feeding molasses on top of the uncut hay was not satisfactory since the lambs in reaching for the leafy portions of the hay at the bottom of the troughs became covered with the sticky feed.

Each lot had access to fresh water supplied by an underground pipe line from a deep well. The water was relatively warm even during the coldest days. The lots at first were bedded with straw to a depth of about four inches at the time the lambs were put into the lots. After that, refuse hay was used, enough being added from time to time to keep the lots dry and the lambs clean. As fresh hay was fed in liberal quantities the lambs did not eat any of the bedding.

PART I

- (A) First, second and third cuttings of alfalfa hay compared.
- (B) First cutting sweet clover hay compared with first cutting alfalfa hay.

DISCUSSION OF RESULTS:

The first and third cuttings of alfalfa hay produced practically the same results as far as finish is concerned. First cutting hay resulted in a daily gain of .246 lbs. per lamb at a cost of \$6.78 per cwt. (See Table IV.) A gain of 100 lbs. was produced with less grain and hay and the gain was more economical than with the other two cuttings fed. The third cutting was next in feeding value, the lambs producing 100 lbs. gain at a cost of \$7.199, making an average daily gain of .235 lbs. per lamb. Second cutting alfalfa hay ranked third. Lambs receiving this roughage made average daily gains of .214 lbs. They were least economical, the gains costing \$7.62 per cwt., which is \$.846 above that of the first cutting hay and \$.425 above that of the third cutting hay. If first cutting alfalfa hay and shelled corn are valued at \$5.00, and \$27.50 per ton respectively, then third cutting hay on the basis of hay fed is worth \$4.26. A direct comparison is possible here in view of the fact that both roughages produced the same market finish and the lambs in the two lots were appraised the same at \$12.00 per cwt.

The comparison of first and second cuttings of hay involves a new factor. Lot I was appraised at \$12.00 per cwt, while Lot II, because of a poorer finish was valued at only \$11.80. When a comparison of the roughages fed the two lots is made on the basis of the feed requirement per hundred weight gain, a correction of \$.20 must be added to the requirement of Lot II to account for the lower valuation

of this lot. On this basis when first cutting hay is valued at \$5.00 and corn at \$27.40 per ton, second cutting alfalfa hay is worth \$3.17 per ton. Such a comparison based on lots of 100 and of 50 lambs respectively indicates that if first cutting hay is considered 100 per cent, then second cutting is only 63 per cent and third cutting 85 per cent as valuable.

Following the same method of comparison if first cutting alfalfa hay is valued at \$5.00, then sweet clover is worth \$6.14 or has a value of 123 per cent that of first cutting alfalfa hay.

The lambs in this test made fairly good and uniform gains. The proportion of poorer lambs was equally divided. At the end of the test there were fewer fat lambs in the lot receiving second cutting hay than in those receiving first and third cuttings. The results are reliable enough to rank the cuttings namely, 1st, 3rd, and 2nd, in order of their feeding value.

A summary of data for each lot is presented in Table IV.

TABLE IV
(a) THREE CUTTINGS OF ALFALFA HAY COMPARED
(b) SWEET CLOVER RESULTS COMPARED WITH THOSE FOR ALFALFA.

Lot I—100 lambs. All other lots, 50 lambs each.

No. of Cutting Lot No.	Cuttings of Alfalfa Hay			Sweet Clover Hay
	First I	Second II	Third III	First IV
* Ave. Weight and Gains (Pounds)				
Initial Weight	65.62	62.59	65.44	62.91
Final Weight	80.38	75.46	79.55	80.55
Total Gain	14.76	12.87	14.11	17.64
Daily Gain	.246	.214	.235	.294
Average Daily Ration (Pounds)				
Grain	.745	.745	.745	.745
Hay { (Fed).....	2.587	2.444	2.685	3.172
(Refused).....	.509	.388	.455	.952
(Consumed).....	2.078	2.056	2.230	2.220
Pounds Feed Per Cwt. Gain				
Corn (Shelled)	302.84	348.13	317.02	253.40
{ Consumed.....	844.70	960.75	948.94	755.10
Hay { Refused.....	206.91	181.31	193.62	323.81
{ Fed.....	1,051.61	1,142.06	1,142.56	1,078.91
Feed Cost per cwt. gain				
Basis feed fed	\$6.778	\$7.624	\$7.199	\$6.617
Appraised Value per 100 lbs.....	\$12.00	\$11.80	\$12.00	\$12.00

* Initial weight refers to the average of three consecutive daily weighings the middle date of which succession marks the beginning of the experiment.

NUTRIENT CONTENTS OF RATIONS

The succeeding table aims to stress a comparison of the daily rations actually fed on the basis of their content of digestible crude protein and total digestible nutrients. In this respect there is no large apparent difference between lots I to IV inclusive. All the feeds were fed at the point of their greatest effectiveness, in a ration that was properly balanced and if anything a little high in protein. The figures for pounds of feed and of dry substance consumed daily per lamb are also included.

TABLE V
AVERAGE RATIONS ACTUALLY FED DURING TEST OF 60 DAYS
(Rations Taken From Table IV.)

Feeds Kind	Feed Lbs.	Total Dry Substance Lbs.	Diges. Crudi Protein Lbs.	Total Diges. Nutrients Lbs.	Nutritive Ratio—1:
LOT I.					
Corn	.745	.679	.044	.635	
Alfalfa Hay					
1st Cutting	2.078	1.940	.190	1.058	
Total	2.823	2.619	.234	1.693	6.05
LOT II.					
Corn	.745	.679	.044	.635	
Alfalfa Hay					
2nd. Cutting	2.056	1.940	.196	1.058	
Total	2.801	2.619	.240	1.693	6.05
LOT III.					
Corn	.745	.679	.044	.635	
Alfalfa Hay					
3rd Cutting	2.230	2.081	.205	1.095	
Total	2.975	2.760	.249	1.730	5.94
LOT IV.					
Corn	.745	.679	.044	.635	
Sweet Clover Hay					
1st. Cutting	2.220	2.074	.208	1.097	
Total	2.965	2.753	.252	1.732	5.87

In rations of such similarity the comparisons of roughages are of greater value than when the rations are unbalanced.

PART II. LIGHT AND HEAVY GRAIN RATIONS COMPARED INTRODUCTION

Large quantities of alfalfa hay and comparatively smaller quantities of grain are produced in the irrigated districts of Washington. The corn crop is ever increasing in importance, as it fits into the rotations

and yields heavily especially for ensiling purposes. It is likely to retain this important position among the available feeding-stuffs. In consequence the profitable marketing of these feeds is a problem of considerable importance and magnitude in irrigated sections.

With the general agreement that addition of some grain to the ration is desirable, the question of how much grain to feed still remains an open issue. Unless the western market discriminates sharply between lambs of fair and good conditions, and pays an appreciable premium for the latter, the feeding of heavy grain rations in order to secure a good finish is apt to be unprofitable. With a fluctuating grain and lamb market, the value of tangible figures serving as a basis for determining how much grain may be fed with profit for any set of conditions, is very evident.

All of the feeder lambs came from the range and were wholly unaccustomed to corn. When offered corn the first time they ate it, but their appetite for this feed seemed to increase during the progress of the feeding period. The lambs started on $\frac{1}{8}$ lbs. of corn per head daily and this quantity was increased at the rate of 1-5 lbs each day until the lambs were on full feed.

Table VI contains the summary of feeding tests with light and heavy grain rations.

TABLE VI.
LIBERAL VS. LIMITED GRAIN RATIONS
Lot I. 100 lambs. All others, 50 lambs each.
Weights and Gains

Corn Fed Lot No.	1½ lb. V	1 lb. VI	¾ lb. I	½ lb. VIII	XIII ¼ lb.
Average Weights and Gains (Pounds)					
Initial Weight	63.04	63.28	65.62	63.35	63.61
Final Weight	84.14	81.24	80.38	76.44	76.79
Total Gain	21.10	17.96	14.76	13.09	13.18
Daily Gain	.352	.299	.246	.218	.220
Average Daily Ration (Pounds)					
Grain	1.354	.960	.745	.500	.277
Hay					
(Fed)	2.428	2.374	2.587	2.625	2.789
(Refused)	.595	.455	.509	.415	.377
(Consumed	1.833	1.919	2.078	2.210	2.412
Pounds Feed per Cwt. Gain					
Corn					
(Shelled)	384.65	321.07	302.84	229.36	125.91
Hay					
(Consumed) ..	520.73	641.80	844.70	1013.75	1096.36
(Refused)	169.03	152.17	206.91	190.36	171.47
Hay Fed	689.76	793.97	1051.62	1024.13	1267.83
Feed Cost Per Cwt.					
(Basis Feed					
Fed).....\$	7.014	\$ 6.384	\$ 6.778	\$ 6.152	\$ 4.895
(Appraised					
Value Per					
Cwt)	\$ 12.50	\$ 12.50	\$ 12.00	\$ 11.35	\$ 11.25

DISCUSSION OF RESULTS

The foregoing table shows that Lots V, VI, I, VIII, and XIII received rations approximating $1\frac{1}{2}$, 1, $\frac{3}{4}$, $\frac{1}{2}$ and $\frac{1}{4}$ pounds of shelled corn respectively with all of the alfalfa hay they would consume. The average daily gains are in proportion to the quantity of concentrates fed with the exception of lots VIII and XIII, there being no such correlation. The two lots gained equally well even though fed $\frac{1}{2}$ and $\frac{1}{4}$ pounds grain respectively.

The appraised values based very largely on condition and character of fleshing are in proportion to the quantity of grain fed, being highest for the lot receiving $1\frac{1}{2}$ lbs. and 1 lb. of shelled corn. The feed required per 100 lbs. gain as well as the average daily feed consumed show that as the grain consumption increases, hay consumption decreases. Lot V consumed an average of 384.65 lbs. of shelled corn and 520.73 lbs. of alfalfa hay to make 100 lbs. gain at a cost of \$7.014. Lot XIII receiving .277 lbs. shelled corn per head daily required only 125.91 lbs of corn and 1096.36 lbs. alfalfa hay to make 100 lbs. gain at a cost of \$4.895. The lambs in Lot V were appraised at \$12.50 per cwt., while those in Lot XIII were valued at only \$11.25. If the lambs are valued at \$6.00 per cwt., in the feed lot at the beginning of the test, the gross profit per lamb in the high grain lot is \$5.259 and in the low grain lot \$4.177. A discrimination of \$1.25 per cwt. in favor of the better finished lambs is more than sufficient to justify the liberal grain feeding at the existing grain prices. It shows that the cheaper gains in weight do not necessarily return the greater profit.

NUTRIENT CONTENT OF RATIONS

The rations of the various lots differed in quantity of corn fed per head daily, from .277 lbs up to 1.354 lbs. The quantity of protein in all rations is relatively constant varying from .237 lbs. to .251 lbs. per head daily. However the greater the quantity of corn fed the greater is the content of the ration in total digestible nutrients. The low grain lot receiving .277 lbs. of corn per head daily consumed 1.464 lbs. of total digestible nutrients while the high grain lot being fed 1.354 lbs. of corn consumed 2.088 lbs. of total digestible nutrients. As the grain consumption increased, the quantity of hay consumed decreased. Since the hay in this case was the protein rich feed, it follows that the high grain rations contained a smaller proportion of protein

than those containing smaller quantities of grain. The nutrient content of the rations is shown in the succeeding table.

TABLE VII
AVERAGE RATIONS ACTUALLY FED DURING TEST

(Taken From Table V)

Feeds	Pounds Feed	Total Dry Substance	Diges. Crude Protein	Total Diges. Nutrients	Nutritive Ratio
LOT V	lbs.	lbs.	lbs.	lbs.	1:
Corn	1.354	1.234	.079	1.154	
Alfalfa Hay 1st. Cutting	1.833	1.711	.172	.934	
Total	3.187	2.945	.251	2.088	7.30
LOT VI					
Corn	.960	.875	.056	.818	
Alfalfa Hay 1st Cutting	1.919	1.792	.181	.977	
Total	2.879	2.667	.237	1.795	6.50
LOT I					
Corn	.745	.679	.044	.635	
Alfalfa Hay 1st. Cutting	2.078	1.940	.196	1.058	
Total	2.823	2.619	.240	1.693	6.05
LOT VIII					
Corn	.500	.456	.029	.426	
Alfalfa Hay 1st. Cutting	2.210	2.063	.208	1.126	
Total	2.710	2.519	.237	1.552	5.5
LOT XIII					
Corn	.277	.252	.016	.236	
Alfalfa Hay 1st Cutting	2.412	2.252	.226	1.228	
Total	2.689	2.504	.242	1.464	5.05

PART III

A STUDY OF THE VALUE OF SILAGE IN LAMB RATIONS

INTRODUCTION

In numerous sections of this State the alfalfa hay crop is so easily produced and of so much importance that the advisability of producing corn, the highly adapted silage crop, is questioned. During periods of low priced hay the feeding of silages is not always economical. However, it is of interest as a means of marketing hay more efficiently when prices are good.

The effect of silage in lamb rations was studied by comparing rations composed of $1\frac{1}{2}$ lbs. and $\frac{3}{4}$ lbs. corn, and 1st cutting alfalfa hay with similar ones where $1\frac{1}{2}$ lbs. of corn silage per head was fed with all additional 1st cutting hay that the lambs would consume. Two series of three lots each were fed on $1\frac{1}{2}$ lbs. and $\frac{3}{4}$ lbs. of concentrates, respectively. One lot in each series received straight first cutting alfalfa hay. The second lot in each series was fed a pound and a half of corn silage with all the hay they would consume in addition. The third lot of each series received the same treatment as the second lot with the exception that cottonseed meal was added to the ration in the proportion of 1 part of this supplement to 7 parts of corn.

Such a plan enables a direct comparison of straight hay ration with a silage hay ration when the quantity of concentrates is $\frac{3}{4}$ lbs. and $1\frac{1}{2}$ lbs. per lamb daily. A comparison of straight hay ration with one containing cottonseed meal, silage and hay with varying quantities of corn is also possible. The cottonseed meal was added to bring up the protein content of the silage hay ration to the level of the straight hay ration. This was considered advisable in view of the lower protein content of the ration containing corn silage. A third comparison of a ration of corn-hay-silage with one of corn-hay-silage to which cottonseed meal is added is facilitated and is of value in determining the advisability of feeding this protein rich feed in a silage ration when roughages are cheap and nitrogenous concentrates relatively high priced.

The data for the 60 day test with lots of 50 lambs each are brought together for comparison in the succeeding table. (Table VIII.)

TABLE VIII
TO STUDY THE VALUE OF SILAGE IN LAMB RATIONS

Series I		Series II							
1½ lbs Corn Per Lamb		% lb. Corn Per Lamb							
V		IX		XI		X		XII	
Corn	Hay	Corn	Hay	Corn	Hay	Corn	Hay	Corn	Hay
C. S. M. 1		C. S. M. 1		C. S. M. 1		C. S. M. 1		C. S. M. 1	
Average Weight and Gains (Pounds)									
Initial Weight	63.04	62.91	63.73	65.618	62.50	63.84			
Final Weight	84.14	87.18	87.24	80.382	82.41	80.52			
Total Gain	21.10	24.27	23.51	14.764	19.91	16.68			
Daily Gain	.352	.404	.392	.246	.332	.278			
Average Daily Ration Per Head (Pounds)									
Grain	1.354	1.354	1.354	.745	.745	.745			
Hay	2.428	1.408	1.260	2.587	1.870	1.801			
Fed	.595	.706	.746	.509	.568	.628			
Refused	1.833	.702	.514	2.078	1.302	1.173			
Consumed	.....	1.355	1.355	1.355	1.355	1.355			
Silage (Corn)	.....	.....	.....	.....	.....	.....			
Pounds Feed Per Cwt. Gain									
Corn	384.65	385.15	302.29	302.84	224.39	267.98			
*C. S. M.	.....	.....	43.11	.....	.....	33.45			
Hay	520.73	173.76	131.12	844.70	392.16	421.94			
Refused	169.03	174.75	190.30	206.91	171.08	225.90			
Silage	.....	335.39	345.66	.....	408.13	487.40			
Feed Cost per Cwt. Gain. Basis									
Feed Fed	\$ 6.994	\$ 5.882	\$ 6.563	\$ 6.778	\$ 4.992	\$ 6.820			
Appraised Value Per Cwt.	\$ 12.50	\$ 12.00	\$ 12.50	\$ 12.00	\$ 11.90	\$ 11.70			
C. S. M.—Cottonseed Meal.									

DISCUSSION OF RESULTS

In the first series of 3 lots (Lots V, IX and XI) receiving $1\frac{1}{2}$ lbs. of concentrates, it is apparent that the addition of $1\frac{1}{2}$ lbs. silage to the ration increases the daily gains and induces economy in cost of the gains. However, this advantage is somewhat offset by a lower valuation of \$.50 per cwt., of the silage fed lambs. The addition of cottonseed meal to the silage-hay ration did not effect the daily gain to any extent. In fact, a falling off of .012 lbs. per head daily was noticed. Owing to the price of \$55.00 per ton of cottonseed meal, this lot made gains at an increased cost of \$.681 per cwt., over that of the hay silage fed lambs. However, the slightly better finish of the lot fed cottonseed meal resulted in a valuation of \$12.50 per cwt., which is \$.50 per cwt., above that of the lambs receiving no cottonseed meal. The condition of the lambs fed corn and hay was as good as of those receiving corn-cottonseed meal-hay and silage. This is largely explained by the fact that the alfalfa hay of the irrigated sections is of exceptionally good quality. There is no apparent benefit derived by the addition of cottonseed meal.

The second series of 3 lots (Lots I, X, and XII) receiving $\frac{3}{4}$ lb. of concentrates, affords a contrast in the daily gains made. In this series the daily gains per lamb vary between .246 lbs. and .332 lbs. For the first series receiving $1\frac{1}{2}$ lbs. of concentrates the daily gains per head vary between .352 and .404 lbs. It is very evident that the daily gains of lambs fed $1\frac{1}{2}$ lbs. concentrates are on a higher level than of those fed only $\frac{3}{4}$ lbs grain.

Similar comparisons made with the second series as with the first show again an advantage of adding silage to a straight hay ration. The straight hay lot made a gain of 100 lbs at a cost of \$6.778 while the hay-silage lot cost only \$4.992. The difference of \$1.786 is partly offset by a lower valuation of 10 cents for the silage fed lambs. However, the discrimination on the basis of market value between straight hay and silage-hay fed lambs is not as great on a lower grain level (in this case $\frac{3}{4}$ lbs. per head daily) as with a higher one. The addition of cottonseed meal to the ration produced greater gains by only .032 lbs., and resulted in a valuation of \$.30 per cwt., lower than of a straight hay lot. The financial returns for this, too, were less than that of any other lot in both series. With a high quality leguminous roughage combined with silage and a low grain feed of $\frac{3}{4}$ lbs. corn per lamb daily, the addition of cottonseed meal is even less advisable than when the corn ration is $1\frac{1}{2}$ lbs. per head daily.

NUTRIENT CONTENT OF RATIONS

When silage replaces more than one-half of the alfalfa hay in a lamb's ration, receiving a liberal feed of corn, a deficiency in protein is likely to result since a non-nitrogenous roughage is being substi-

tuted for a highly nitrogenous one. The ration of lot IX in the following table contains only .149 lbs. crude protein. The ration of lot V where only alfalfa hay and corn are fed contains .251 lbs. or practically twice as much. The ration of lot XI is higher in protein than that of lot IX since 1/7 of the concentrate is in the form of cottonseed meal. However, even such a quantity of the nitrogenous concentrate was not sufficient to increase the protein content of the ration to the level of the alfalfa-hay-corn ration.

TABLE IX
AVERAGE RATIONS ACTUALLY FED DURING TEST OF 60 DAYS
(Rations Taken From Table VI)

Feed	Pounds Feed	Total Dry Substance	Diges. Crude Protein	Total Diges. Nutrients	Nutritive Ratio
LOT V		lbs.	lbs.	lbs.	1:
Corn	1.354	1.234	.079	1.154	
Alfalfa Hay					
1st Cutting	1.833	1.711	.172	.934	
Total	3.187	2.945	.251	2.088	7.3
LOT IX					
Corn	1.354	1.234	.079	1.154	
Alfalfa Hay					
1st Cutting	.702	.655	.066	.358	
Corn Silage	1.355	.538	.004	.343	
Total	3.411	2.427	.149	1.855	11.4
LOT XI					
Corn	1.185	1.080	.069	1.010	
Cottonseed Meal	.169	.154	.049	.125	
Alfalfa Hay					
1st. Cutting	.514	.480	.048	.262	
Corn Silage	1.355	.538	.004	.343	
Total	3.223	2.252	.170	1.740	9.2

Where the quantity of corn fed is .745 lbs. as compared to 1.354 lbs the hay consumption even when accompanied by a liberal silage feeding is high enough to insure a fair sufficiency of protein. For this reason in this series consisting of lots I, X, and XII, the nutritive ratios vary only from 1 to 6 up to 1 to 8.6. In the foregoing series where lots V, IX, and XI are compared, and where the concentrated feed is twice as large, the nutritive ratios vary from 1 to 7.3 up to 1 to 11.4.

TABLE X
AVERAGE RATION ACTUALLY FED DURING TEST OF 60 DAYS
(Rations Taken From Table VI)

Part B.

Feeds	Feed Lbs.	Total Dry Substance Lbs.	Diges. Crude Protein Lbs.	Total Diges. Nutrients Lbs.	Nutritive Ratio
LOT I.					1:
Corn	.745	.679	.044	.635	
Alfalfa Hay					
1st Cutting	2.078	1.940	.196	1.058	
Total	2.823	2.619	.240	1.693	6.0
LOT X					
Corn	.745	.679	.044	.635	
Alfalfa Hay					
1st Cutting	1.302	1.212	.123	.663	
Corn Silage	1.355	.538	.004	.343	
Total	3.402	2.429	.171	1.641	8.6
LOT XII					
Corn	.652	.594	.038	.556	
C. S. M.	.093	.085	.027	.069	
Alfalfa Hay	1.173	1.095	.110	.597	
Corn Silage	1.355	.538	.004	.343	
Total	3.273	2.312	.179	1.565	7.7

PART IV

**BET MOLASSES COMPARED WITH CORN WHEN IT REPLACES
ONE THIRD OF THE CONCENTRATES
INTRODUCTION**

Beet molasses is available at the beet sugar factories in Yakima Valley sections. During many recent periods the prices of molasses and grain have been out of proportion with their feeding value. The molasses has been so cheap, that it could be used to replace a part of the concentrates with economy despite the necessary cumbersome methods involved in feeding it. During the recent feeding test it was purchased at \$14.80 per ton, delivered on the farm with corn costing \$27.40 per ton on the same basis. Its content of 1.1 lbs. digestible protein and 57.1 therms of net energy per 100 lbs. as compared with 7.5 lbs. protein and 85.5 therms for corn, in view of the quoted prices shows it to have a place in the fattening ration of lambs.

In Table XI the summary of the trial shows strikingly the economy of gains produced by molasses feeding.

TABLE XI
BEEF MOLASSES COMPARED WITH CORN

Concentrates Fed		Corn	Corn & Molasses
Lot No.		V	XIV
Average Weights and Gains (Pounds)			
Initial Weight		63.04	61.951
Final Weight		84.14	83.37
Total Gain		21.10	21.42
Daily Gain		.352	.357
Average Daily Ration (Pounds)			
Grain		1.354	.960
Molasses			.483
Hay {	Fed	1.833	1.626
	Refused	.595	.738
	Consumed	2.428	2.364
Pounds Feed Per Cwt. Gain			
Corn (Shelled)		384.66	268.91
Molasses (Beet)			135.29
Hay {	Fed	689.77	662.18
	Refused	169.03	206.72
	Consumed	520.74	455.46
Feed Cost per Cwt. Gain			
(Basis Feed Fed)	\$ 6.994		\$ 6.338
Appraised Value Per Cwt.	\$ 12.50		\$ 12.25

DISCUSSION OF RESULTS

Results of the 60 day test show that the rate of gain on both rations was almost the same. The molasses in the ration, because of its appetizing qualities resulted in a slightly greater hay consumption. The straight grain lot made gains at a cost of \$6.994, which is \$.656 higher than that for the molasses lot. However, the corn lot was slightly better fleshed than where molasses was fed, its appraised value being \$12.50 per cwt., which is \$.25 higher than that for the lot receiving molasses.

From the feed requirements per hundred weight gain given in the foregoing table, it is evident that on the basis of hay fed, 135.29 lbs., beet molasses equaled in feeding value 115.75 lbs. corn plus 27.59 lbs. alfalfa hay. If Corn and alfalfa hay are valued at \$27.40 and \$5.00 per ton, respectively, then beet molasses on the basis of the foregoing figures is worth \$24.39 per ton. Such a comparison rests on the assumption that the two groupings of feeds have each produced 100 lbs. gain. However, in this instance these gains had a different commercial value so that by applying the correction for the poorer finish produced by the molasses its actual value would fall slightly below the above figure.

NUTRIENT CONTENT OF RATIONS

The quantity of digestible protein in both rations is the same. The ration of lot XIV is slightly lower in digestible protein because molasses was substituted for corn. As a result the nutritive ratio is 1 to 6.3 in contrast to 1 to 7.3 for the corn-alfalfa hay ration.

TABLE XII
AVERAGE RATIONS ACTUALLY FED DURING TEST
(Rations Taken From Table VII)

Feeds	Pounds Feed	Total Dry Substance	Diges. Crude Protein	Total Diges Nutrients	Nutritive Ratio
LOT V					1:
Corn	1.354	1.234	.079	1.154	
Alfalfa Hay					
1st. Cutting	1.833	1.711	.172	.934	
Total	3.187	2.945	.251	2.088	7.3
LOT XIV					
Corn	.960	.896	.090	.818	
Molasses	.483	.385	.025	.309	
Alfalfa Hay					
1st. Cutting	1.626	1.518	.153	.828	
Total	3.069	2.799	.268	1.955	6.3

SUMMARY

PART I.

1. Comparisons based on lots of 100 and of 50 lambs indicate that if first cutting hay is considered as 100 per cent, then second cutting hay is only 63 per cent and third cutting 85 per cent as valuable for fattening lambs.
2. On the same basis first cutting sweet clover cut for hay when at a height of 24 to 30 inches has a value of 123 per cent.
3. There were fewer fat lambs in the lot receiving second cutting alfalfa hay than in those receiving first and third cuttings at the end of the test.
4. The rations for lambs fed the three different cuttings of alfalfa hay and sweet clover were practically identical in their content of digestible protein and total digestible nutrients. This constitutes a fair basis for comparing the roughages.

PART II.

1. The feed required for 100 lbs. gain as well as the average daily feed consumed show that as the grain consumption increases, hay consumption decreases.
2. The largest returns per lamb resulted with the most liberal grain feeding. The test shows that the cheaper gains do not necessarily return the greater profit, because of a lower market valuation of the poorer finished lambs fed the cheaper rations.

3. In the two lots of 50 lambs each, fed $\frac{1}{2}$ and $\frac{1}{4}$ lbs. corn per head daily, equal gains were obtained. There was not much difference in finish.
4. The greater the quantity of corn fed, the greater is the content of the ration in total digestible nutrients. As the grain consumption increased, the hay consumption was less and since hay is the protein rich feed, it follows that the high grain rations contain a smaller proportion of protein than those containing the lower quantities of grain.

PART III.

1. There is a decided advantage resulting from the addition of $1\frac{1}{2}$ lbs. of corn silage to corn-alfalfa hay rations for fattening lambs. It increases the daily gains and induces economy in the cost of gains especially when the silage can be produced at half the price of hay.
2. The addition of cottonseed meal to corn-alfalfa hay silage ration, resulted in an increased cost of gains with no apparent effect on the extent of the daily gains over lots fed no cottonseed meal. Furthermore the finish was not quite as good.
3. With a high quality leguminous roughage, combined with silage and $\frac{3}{4}$ lb. corn per head daily, the addition of cottonseed meal is even less advisable than when the corn ration is $1\frac{1}{2}$ lbs. per head daily.

PART IV

1. Lambs fed .483 lbs. beet molasses and .960 lbs. of corn per head daily made as good gains as those fed 1.354 lbs. corn. Good first cutting alfalfa hay was fed in addition.
2. The molasses in the ration, because of its appetizing qualities resulted in a slightly greater hay consumption.
3. The test shows that 135.29 lbs. beet molasses had the same feeding value as 115.89 lbs. corn plus 65.60 lbs. alfalfa hay.
4. If corn and alfalfa hay are valued at \$27.40 and \$5.00 per ton, respectively, then beet molasses on the basis of the foregoing figures is worth \$24.39 per ton.
5. The lambs fed corn and beet molasses although making as good gains as those fed straight corn sold at \$.25 per cwt., less than the corn lot because of the slightly lower finish.

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**STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON**

**DIVISION OF PLANT PATHOLOGY
AND
AGRICULTURAL ENGINEERING**

**The Dusting of Wheat for Bunt
or Stinking Smut**

**BY
F. D. HEALD AND L. J. SMITH**

**BULLETIN No. 171*
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*** A revision of Bulletin No. 168 so as to include the experimental results
secured in 1922.**

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THE DUSTING OF WHEAT FOR BUNT OR STINKING SMUT

By F. D. Heald and L. J. Smith

Introduction

In the control of wheat smut we have passed through two periods: first the bluestone or copper sulphate period from the earliest times up to 1897, when formaldehyde was first employed; and second, the formaldehyde period from 1897 to the present time. Although the formaldehyde disinfection has very largely replaced the use of bluestone in the eastern United States, the latter has continued to be used quite extensively in the Pacific Northwest since it has been shown to have some effect in reducing the smut in winter wheat due to soil contamination, while formaldehyde has no residual action.¹ Although both bluestone and formaldehyde treatments have proved effective in preventing bunt of wheat due to seed-borne spores, both have certain disadvantages and their employment is frequently followed by injurious effects upon the crops.

Disadvantages of and Objections to the Standard Wet Treatments

It has long been recognized that the use of the various bluestone formulae² causes much reduction in the per cent of germination of treated wheat. Even with close attention to standard recommendations, treated seed may frequently show as low as only 25 to 35 per cent viable, while reductions to 40 to 60 per cent viable are rather common. In addition to the killing effect of the bluestone, there may be a pronounced retardation of growth and a lowered vitality. Young seedlings may be twisted and crippled and the toxic effects persist or are only slowly outgrown. When first introduced formaldehyde was eagerly accepted as a substitute for bluestone since it was claimed to do away with the seed injury. It had the added recommendation of being cheaper and also more convenient, since it is a solution of gas in water and ready to use by diluting to the proper strength. With continued use formaldehyde has also been found to have injurious effects. The reduction in germination per cent of the treated grain may be very slight, especially if the seed is

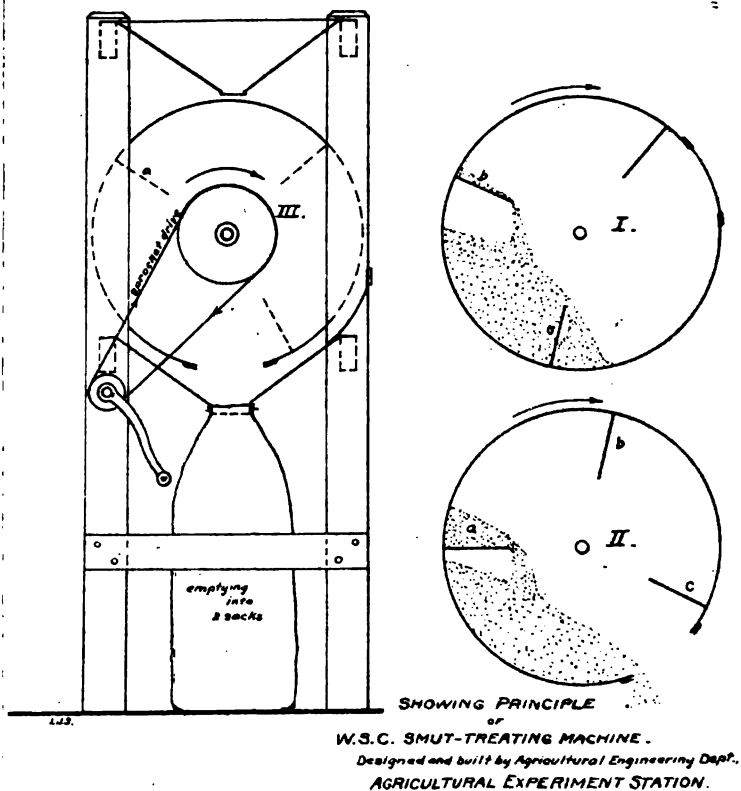


Fig. 1. Diagram showing the principle of the smut-treating machine.. Patents applied for by the Washington Experiment Station, State College.

planted at once in a moist soil, but injury is much more pronounced if the seed is allowed to dry before seeding or if it is seeded in dry soil² where it must wait for rains before germination.

It has long been known that an afterbath of bluestone-treated wheat with milk of lime greatly lessens the amount of seed injury, and it has recently been shown that the same method is effective in lessening the injury from formaldehyde. The work of Brauns³ in 1920 showed that pre-soaking would accomplish the same results. While these methods reduce the seed injury and have been recommended for general use, they do not entirely eliminate the depressing effects of the bluestone treatment.

The methods of steeping grain in bluestone or in formaldehyde are inconvenient. The handling of the wet sacks of grain is a disagreeable operation, while the necessity for immersing in two successive baths is an added burden. The necessity for treating grain shortly before seeding, with special precautions concerning drying, makes both of the wet treatments objectionable. The nature of the disinfection has called for the more laborious open-tank method when the seed was heavily smutted. Grain treated by a wet method must also be protected from freezing.

Historical Statement Concerning the Use of Copper Carbonate

Copper carbonate as a fungicide for seed disinfection had been disregarded as its extreme insolubility in water was thought to exclude the possibility of effective action. In the form of a finely powdered dust it was first tested by Darnell-Smith⁴ in New South Wales as a fungicide in the control of wheat smut. On the basis of tests conducted in 1915 and 1916 he reported in 1917 that copper carbonate dust gave better results than either formaldehyde or bluestone. A more complete report was issued in 1919, with the claim that machine-treated grain was free from smut while hand-treated grain showed a slight amount of smut. The copper carbonate dust treatment caused no injury to seed or to young plants and also resulted in very substantial increases in yield⁵. The results of Darnell-Smith were questioned by Perkins⁶ in 1919 who stated that "we can not, for instance, imagine that a substance wholly insoluble in water can have high fungicidal properties." A discussion of this criticism was published by Darnell-Smith⁷ in 1921.

The excellent results obtained in Australia soon attracted the attention of American investigators. Mackie and Briggs⁸ first reported experiments in California which corroborated the reports from Australia. They reported in 1921 that spring wheat treated with 2 ounces of copper carbonate dust per bushel was free from



Fig. 2. View of machine and wagon with sack of wheat being emptied into the drum.

smut and suffered no reduction in germination, while the untreated check gave 6.2 per cent of smutted heads.

Lambert and Bailey⁹ have just recently reported perfect control of both bunt of wheat and smut of oats by using 2 ounces of copper carbonate dust per bushel. No reduction in germination of oats resulted from using 2 ounces per bushel, while 2 to 10 ounces of the copper carbonate caused no appreciable injury to wheat.

The results from the use of copper carbonate in spring wheat plantings of 1921 were reported by Heald and Smith¹⁰ in June 1922. These results as well as the description of the Washington State College smut-treating machine are repeated in the present bulletin.

Coons¹¹ has recently reported favorably on the use of copper carbonate for the control of stinking smut in winter wheat in Michigan. Since soil contamination is not a factor in that region, the results can only be compared with our spring seedings.

Comparative Seed Treatments, 1921

Since the favorable results reported by other workers have been substantiated by our own experiments, it has seemed advisable to issue this revised report. The experiments to be reported here covered the seasons of 1921 and 1922.

In our preliminary experiments two varieties of wheat, Blue-stem and Jenkins Club, were selected for test. The grain was artificially smutted, using 1 gram of smut to each 100 grams of seed. This is the amount of smut determined by previous experiments¹⁰ as necessary to cause fairly heavy smut but not the maximum amount. The smut was applied by shaking smut and seed together in a large jar; after which the smutted seed was divided into smaller lots, each of which received one of the treatments specified. Each lot was planted in the field in rod rows of carefully spaced seed, and greenhouse germination tests were made to determine the amount of seed injury from the respective treatments. Head and plant counts of the field plots were made at harvest time.

TABLE I.
Comparison of Dust and Wet Seed Treatments
Spring Seeding, 1921

Treatment	BLUESTEM			JENKINS CLUB		
	Per cent germin- ation	Per cent smutted plants	Per cent smutted heads	Per cent germin- ation	Per cent smutted plants	Per cent smutted heads
Check, untreated	84.25	15.06	13.6	89.5	4.6	3.2
Bluestone, wet	67	0	0	65.5	1.2	0.4
Formaldehyde, wet	38.5	0	0	53.5	1.1	0.7
Chorophol, wet	94.5	0	0	96	0	0
Copper carbonate 2 oz. Dust	91.5	0	0	92	0	0
Copper carbonate 4 oz. Dust	98.5	0	0	96.5	0	0
Copper sulphate +) calcium carbonate) (equal parts)						
2 oz. Dust	92.5	0	0	94.5	0	0
Sulphur. 10 lbs. "	89.	0.5	0.2	92.	0	0
Sulphur. 20 lbs. "	94.	0	0	93.5	0	0

The relatively low per cent of smut in both of the checks is explained by the high temperatures and dry conditions immediately following planting, while the smaller amount of smut in the Jenkins Club plots was due to the proximity of these to a row of willow trees which drew very heavily on the soil moisture. It may be noted that perfect control of the smut was obtained by copper carbonate dust and also by the mixture of finely powdered anhydrous copper sulphate (bluestone) and powdered calcium carbonate. The latter mixture will result in the formation of copper carbonate as soon as the



Fig 3. View with drum of machine in position to show the opening and one of the radial mixers or buffers.

treated grain comes in contact with soil moisture and would therefore be expected to give results similar to an initial application of copper carbonate dust. These dust treatments have given an improved germination of the wheat when contrasted with bluestone and formaldehyde disinfection. The value of sulphur dust in smut control is still open to question. Even if it should continue to give the

protection as indicated by these tests, increased yields would be necessary to justify the expense of using the large amount of sulphur.

Comparative Seed Treatments, Spring Wheat, 1922

In the spring plantings of 1922, three varieties were used, Marquis, a resistant "vulgare" type, Bluestem, a susceptible "vulgare" type and Jenkins Club a very susceptible "compactum" type. In each test three different degrees of smutting were employed: light, medium and heavy. The weights of smut per 100 grams of seed and the approximate number of smut spores per grain of wheat were as follows:

Light smut	0.1 grams per 100 gr. of seed, 9,000 spores per grain
Medium smut	0.4 grams per 100 gr. of seed, 36,000 spores per grain
Heavy smut	1.0 grams per 100 gr. of seed, 90,000 spores per grain

The seed was smutted and then treated and planted in the same manner as described in the tests of 1921.

In the first series (Table II), varying quantities of copper carbonate per bushel, from $\frac{1}{2}$ oz. to 3 ozs. were used, in order to determine if possible the minimum quantity necessary to give effective protection. Hydrated lime was used as a diluent for the two lower quantities of carbonate for comparison with the pure copper carbonate. The hydrated lime did not seem to increase the effectiveness of the copper carbonate, but it is significant that one-half ounce per bushel gave nearly as good protection as two ounces. The seed which was heavily smutted was black with smut and was carrying a much larger number of spores than would be found in any ordinary farm practice. The most smut produced by any variety, with medium smutting, even with the reduced quantities of copper carbonate, was 0.9 per cent with an average of 0.21 per cent, while the untreated, medium-smutted lots gave an average of 24.15 per cent of smutted heads. The heavily smutted, treated lots gave an average of 0.97 per cent smutted heads as contrasted with an average of 40.57 per cent smutted heads for the heavily smutted untreated lots. (See Table IV for the untreated checks.)

In a second series of similarly smutted samples (Table III) the seed was treated with varying quantities of finely powdered anhydrous or dehydrated bluestone mixed with equal quantities of finely

powdered calcium carbonate or with hydrated lime. The lots treated with anhydrous bluestone and calcium carbonate gave an average of 1.15 per cent smutted heads, while the corresponding lots treated with anhydrous bluestone and hydrated lime gave an average of 1.65 per cent smut as contrasted with an average of 23.26 per cent in all untreated checks. The average for all copper carbonate tests was 0.41 per cent smutted heads as contrasted with 1.4 per cent smutted heads for all tests with anhydrous bluestone. It seems from these results that anhydrous bluestone is not quite equal to copper carbonate in its protective action and that hydrated lime is not so satisfactory for mixing with the anhydrous bluestone as is calcium carbonate.

In a third series the Corona compound* of copper carbonate was used for comparison with the pure copper carbonate. (Table IV) The average per cent of smutted heads in nine samples given each treatment was as follows:

½ oz. Copper carbonate per bushel,	0.54 per cent smutted heads
1 oz. Copper carbonate per bushel,	0.087 per cent smutted heads
2 ozs. " carbonate per bushel,	0.290 per cent smutted heads
3 ozs. " carbonate per bushel,	0.000 per cent smutted heads
2 ozs. Corona compound per bushel,	0.077 per cent smutted heads
4 ozs. Corona compound per bushel,	0.000 per cent smutted heads
No treatment, No. 1.	17.88 per cent smutted heads
No treatment, No. 2.	28.72 per cent smutted heads

The Corona compound contained 17-18 per cent metallic copper as compared with about 50 per cent in the pure copper carbonate. Two ounces of the Corona compound would therefore contain more metallic copper than one-half ounce of the pure carbonate. On the basis of this single test the Corona compound appears, however, to have a better protective action than pure copper carbonate carrying an equal amount of metallic copper.

Seed-o-San, an organic mercury compound furnished by the Standard Tester Co., Chicago, did not give as good protection as a dust fungicide as the copper dusts, although it was very effective for light and medium smutted samples. (Table IV)

*Furnished by the Corona Chemical Division of the Pittsburg Plate Glass Company, Milwaukee, Wisconsin.

TABLE II.

Results in control of stinking smut using varying quantities of copper carbonate. Spring seeding, 1922.

Treatment	Variety	Degree of Smutting	Percent of heads Smutted
Copper Carbonate $\frac{1}{2}$ oz. per bushel	Marquis	Light	.0
		Medium	.0
		Heavy	.0
	Bluestem	Light	.0
		Medium	.0
		Heavy	.0
	Jenkins Club	Light	.88
		Medium	.0
		Heavy	4.09
Copper carbonate $\frac{1}{2}$ oz. plus hydrated lime $\frac{1}{2}$ oz. = 1 oz. per bushel.	Marquis	Light	.0
		Medium	.0
		Heavy	.0
	Bluestem	Light	.0
		Medium	.18
		Heavy	1.08
	Jenkins Club	Light	.0
		Medium	.62
		Heavy	5.41
Copper carbonate 1 oz. per bushel.	Marquis	Light	.0
		Medium	.0
		Heavy	.0
	Bluestem	Light	.0
		Medium	.79
		Heavy	.0
	Jenkins Club	Light	.0
		Medium	.0
		Heavy	.0
Copper carbonate 1 oz. plus hydrated lime 1 oz. = 2 ozs. per bushel.	Marquis	Light	.0
		Medium	.0
		Heavy	.0
	Bluestem	Light	.36
		Medium	.33
		Heavy	5.01
	Jenkins Club	Light	.0
		Medium	1.0
		Heavy	.14
Copper carbonate 2 ozs. per bushel.	Marquis	Light	.0
		Medium	.0
		Heavy	.0
	Bluestem	Light	.0
		Medium	.0
		Heavy	.89
	Jenkins Club	Light	.0
		Medium	.9
		Heavy	.9

(Continued on next page)

TABLE II.—Continued.

Treatment	Variety	Degree of Smutting	Percent of heads smutted
Copper carbonate 3 ozs. per bushel.	Marquis	Light	.0
		Medium	.0
		Heavy	.0
	Bluestem	Light	.0
		Medium	.0
		Heavy	.0
	Jenkins Club	Light	.0
		Medium	.0
		Heavy	.0

See Table IV. for untreated checks.

TABLE III.

Results in control of stinking smut using varying quantities of anhydrous bluestone. Spring seeding 1922.

Treatment	Variety	Degree of Smutting	Percent of heads smutted
Anhydrous bluestone $\frac{1}{2}$ oz. plus Calcium carbonate $\frac{1}{2}$ oz. = 1 oz. per bushel.	Marquis	Light	.0
		Medium	.0
		Heavy	.0
	Bluestem	Light	.31
		Medium	trace
		Heavy	4.92
	Jenkins Club	Light	.0
		Medium	5.4
		Heavy	.49
Anhydrous bluestone 1 oz. plus Calcium carbonate 1 oz. = 2 ozs. per bushel.	Marquis	Light	.0
		Medium	.0
		Heavy	.0
	Bluestem	Light	.0
		Medium	.27
		Heavy	.74
	Jenkins Club	Light	.37
		Medium	.0
		Heavy	1.15
Anhydrous bluestone 2 ozs. plus Calcium carbonate 2 ozs. = 4 ozs. per bushel.	Marquis	Light	.0
		Medium	.0
		Heavy	.0
	Bluestem	Light	.0
		Medium	.0
		Heavy	4.68
	Jenkins Club	Light	1.28
		Medium	.98
		Heavy	.16

(Continued on next page)

TABLE III.—Continued.

Treatment	Variety	Degree of Smutting	Percent of heads smutted
Anhydrous bluestone $\frac{1}{2}$ oz. plus Hydrated Lime $\frac{1}{2}$ oz. = 1 oz. per bushel.	Marquis	Light	1.11
		Medium	.0
		Heavy	.0
	Bluestem	Light	1.6
		Medium	3.05
		Heavy	10.15
	Jenkins Club	Light	.0
		Medium	2.
		Heavy	.525
Anhydrous bluestone 1 oz. plus Hydrated Lime 1 oz. = 2 ozs. per bushel.	Marquis	Light	.0
		Medium	.0
		Heavy	.0
	Bluestem	Light	.0
		Medium	.0
		Heavy	3.75
	Jenkins Club	Light	.0
		Medium	.825
		Heavy	1.79
Anhydrous bluestone 2 ozs. plus Hydrated Lime 2 ozs. = 4 ozs. per bushel.	Marquis	Light	.0
		Medium	.0
		Heavy	.0
	Bluestem	Light	.0
		Medium	.0
		Heavy	1.62
	Jenkins Club	Light	.88
		Medium	2.54
		Heavy	.0

See Table IV. for untreated checks.

TABLE IV.

Results in control of stinking smut with Corona compound of copper carbonate and Seed-O-San. Checks of untreated smutty seed. Spring seeding, 1922.

Treatment	Variety	Degree of Smutting	Percent of heads smutted
Corona compound of copper carbonate, 2 ozs. per bushel.	Marquis	Light	.0
		Medium	.0
		Heavy	.0
	Bluestem	Light	.0
		Medium	.0
		Heavy	0.25
	Jenkins Club	Light	.0
		Medium	.0
		Heavy	0.45
Corona compound of copper carbonate, 4 ozs. per bushel.	Marquis	Light	.0
		Medium	.0
		Heavy	.0
	Bluestem	Light	.0
		Medium	.0
		Heavy	.0
	Jenkins Club	Light	.0
		Medium	.0
		Heavy	.0
Seed-O-San, 2 ozs. per bushel.	Marquis	Light	.0
		Medium	.0
		Heavy	.0
	Bluestem	Light	.0
		Medium	0.55
		Heavy	3.9
	Jenkins Club	Light	.55
		Medium	.0
		Heavy	1.27
Check No. 1, untreated smutty seed.	Marquis	Light	.61
		Medium	.68
		Heavy	.0
	Bluestem	Light	5.99
		Medium	16.65
		Heavy	54.1
	Jenkins Club	Light	4.2
		Medium	14.3
		Heavy	64.4
Check No. 2, untreated smutty seed.	Marquis	Light	.33
		Medium	.16
		Heavy	1.66
	Bluestem	Light	6.85
		Medium	56.02
		Heavy	62.7
	Jenkins Club	Light	12.4
		Medium	57.8
		Heavy	60.56

Tests with Winter Wheat, 1922.

A series of tests with winter wheat varieties in cooperation with the Division of Farm Crops was started in the fall of 1921 to determine the comparative value of various seed and soil treatments in the prevention of smut. The previous work with bluestone, formaldehyde and copper carbonate had shown nearly perfect control where only seed-borne smut had to be combatted. The following experiments were carried out on typical summer fallow and were intended therefore to show the comparative value of the different treatments in preventing smut originating from the wind-blown spores. Three varieties were used: Hybrid 128, a very susceptible "compactum" type, Turkey Red, a very resistant variety, and Red Russian, a rather susceptible variety. The seed was not smutted artificially, each lot was given the treatment indicated in the tabulation, and seeded in 1/40 acre plots. This series was also designed to give comparative data on the yield. The smut percentage was obtained by counting a single drill row in each plot, the total number of heads varying from 1000 to 4000.

The results are presented in Table V. No reliable conclusions can be drawn from the data on yield, since there was a marked variation in the soil in the different plots. This was especially noticeable in the Red Russian plots. It may be assumed that the smut in the plots treated with formaldehyde 1-40 (8.3 per cent) originated from soil contamination and that the seed used carried but little smut since the average for the untreated seed was 8.64 per cent of smutted heads. Compared with formaldehyde 1-40, which gives no protection from soil-borne smut, all of the treatments except sulphur 200 lbs. per acre, and reploting the summer fallow, show a reduction in the amount of smut as a result of treatment. The differences are not sufficiently pronounced, however, to justify any conclusion from this series as to the superiority of any one treatment. The small amount of smut in the trench seeding is worthy of note, but the low yield is due to the poor stand as compared with other plots as these plots were planted with a garden seeder. The increase of smut in the replowed summer fallow is contrary to our general experience. During the past season a 65-acre field of replowed summer fallow on the farm of H. H. Curtis, near Pullman, showed only 4.5 per cent of smut, as contrasted with, 4 per cent on the normal summer fallow.

A second series, omitting the different cultural practices, was seeded in duplicate rod-row plots in artificially smutted summer fallow. Just previous to seeding, powdered smut was dusted over the field with a Corona duster, giving as uniform a distribution as possible. The soil was therefore carrying much more smut than normal summer fallow. The results are presented in Table VI. Assuming no protective action from the formaldehyde treatments (Average of 25 per cent smutted heads) all of the copper treatments showed a reduction in the amount of smut as a result of the treatments.

During the past year comparative tests of bluestone and formaldehyde with copper carbonate were carried out on farms in different parts of the state, the larger number of the tests being supervised by Mr. G. L. Zundel, Extension Pathologist, with the assistance of County Agents. The appended table (Table VII) is a summary from these tests and others arranged for by the Experiment Station Pathologist. Although there were individual cases in which the old treatments gave better results than copper carbonate, the latter gave better average results in all cases.

TABLE V.

Comparative effect of seed and soil treatments in preventing stinking smut in winter wheat planted in ordinary summer fallow. Fall seeding, 1922.

TREATMENT	HYBRID 128		TURKEY RED		RED RUSIAN		Avege. % Smutted heads for three Varieties
	Percent heads Smutted	Bushels per Acre	Percent heads Smutted	Bushels per Acre	Percent heads Smutted	Bushels per Acre	
Sulphur 200 lbs. per A.	17.5	44.3	1.9	36.5	4.8	27.1	8.02
Untreated	17.4	44.5	1.5	36.3	9.8	25.2	9.56
Sulphur 20 lbs. per bu.	6.6	43.7	0.5	35.4	6.2	26.5	4.43
Copper sulphate sprin- kle 1 lb. to 1 gallon of water	12.5	42.4	trace	34.4	2.7	24.3	5.06
Copper carbonate 2 ozs. per bu.	13.0	43.5	1.4	36.7	3.2	22.8	5.86
Anhydrous copper sul- phate 1 oz. plus cal- cium carbonate 1 oz.	14.8	42.6	0.5	34.9	3.8	21.3	6.36
Copper sulphate 1-5	10.5	37.8	0.6	40.5	3.8	30.9	4.96
Copper sulphate 1-5 plus lime bath	7.1	41.7	0.7	38.9	3.7	37.7	3.83
Formaldehyde 1-40, customary depth	18.6	40.3	0.6	40.4	5.7	39.9	8.3
Formaldehyde 1-40, shallow drilling	10.4	37.4	0.5	31.8	4.6	34.4	5.16
Formaldehyde 1-40, seed broadcasted	16.7	32.8	1.3	36.9	5.1	27.9	7.7
Untreated	14.7	39.2	1.4	48.1	7.1	43.8	7.73
Formaldehyde 1-40, summer fallow re- plowed	21.0	39.7	1.6	46.1	10.8	46.2	11.13
Formaldehyde 1-40, trench seeding	5.6	25.7	.5	26.9	3.9	33.2	3.33

TABLE VI.

Comparative effect of seed treatments in preventing smut in winter wheat planted in artificially smutted summer fallow. Fall seeding, 1921.

TREATMENT	HYBRID 128		TURKEY RED		RED RUSSIAN		Ave. % Heads Smutted
	Total Heads	% Smutted Heads	Total Heads	% Smutted Heads	Total Heads	% Smutted Heads	
Sulphur 200 lbs. per A.	185	43.2	307	0.0	105	20.9	21.3
Sulphur 20 lbs. per bu.	256	50.3	316	0.1	203	28.5	26.2
Formaldehyde 1-40	312	49.6	360	5.2	243	23.8	26.2
Copper carbonate 2 oz. per bu.	453	36.2	278	3.9	280	13.9	18.0
Anhydrous copper sul- phate 1 oz.	248	25	306	6.2	222	24.3	18.5
Calcium carbonate 1 oz.							
Copper sulphate 1-5	164	6	239	4.3	167	27.5	12.6
Copper sulphate 1-5 plus Lime bath	197	21.3	467	2.9	201	22.3	15.5
Formaldehyde 1-40	186	34.4	363	4.4	235	32.3	23.7
Copper sulphate 1-1 Sprinkle	219	15.9	332	1.5	216	15.7	11.03

TABLE VII.
 Smut protection from copper carbonate dust as compared with bluestone and formaldehyde treatments. Farm tests, 1922.

TREATMENTS	No. of Tests	Avg. % Smutted Heads	Maximum % Smutted Heads	No. of tests in which each treatment excelled
Bluestone, standard	26	10.28	31.7	5
Copper carbonate dust 2 oz. per bushel	26	8.47	31.2	21
Bluestone plus Lime bath	8	11.	20.2	1
Copper carbonate 2 ozs. per bushel	8	8.4	12.4	7
Formaldehyde 1-40	20	11.4	35.0	1
Copper carbonate 2 ozs. per bushel	20	5.1	18.7	19

The Effect of Copper Carbonate on Germination and Growth

One of the special values of copper carbonate as a seed fungicide is its non-toxic effect upon the treated grain. The germination tests reported in Table I, show that seed treated with either copper carbonate or anhydrous copper sulphate plus calcium carbonate gave a higher per cent of germination than untreated seed.

The question has been raised as to whether wheat may be dusted with copper carbonate some months previous to seeding time without suffering any injury. In order to test this point, four varieties were given the standard treatment (2 ounces per bushel), and germination tests made at intervals in comparison with untreated seed. The treated and untreated seed was planted in flats in the greenhouse using 200 seed in each lot. The appended table (Table VIII) shows the results obtained up to the present time.

An examination of this table will show not only that no injury resulted for the duration of the test, but that the dusted grain showed an improved germination over the untreated samples.

Mr. Hill, of the Waterville Branch Station, has reported the value of copper carbonate in lessening seed injury for late fall-seeded grain. The data in the appended table (Table IX) are taken from his report, and show the per cent of germination under field conditions. The marked superiority of the copper carbonate over formaldehyde and bluestone is clearly evident.

Besides preventing reduction in germination per cent and thus improving the stand, the copper carbonate treatment induces a more rapid germination and a more vigorous growth. This is especially marked in comparing fields from seed treated with bluestone with fields or plots treated with copper carbonate. In numerous cases of fall-seeded grain, the greater vigor of growth of the copper carbonate-treated field has been very pronounced, even during the early spring. While we have no reliable quantitative data on yields, our cooperators generally agree that the copper carbonate has also given increased yields.

Formula and Methods of Application of Copper Carbonate Dust

On the basis of completed trials our present recommendation is the use of at least 2 ozs. of finely powdered copper carbonate per bushel of wheat. The powder should be fine enough for 98 per



Fig. 4. View of machine with two sacks partially filled. A second lot is treated before the sacks are ready to be removed.

cent. to pass through a 200-mesh sieve and should be of the light fluffy type designed especially for dusting. The heavy copper carbonate, designed for the metallic trades should be avoided. The pure copper carbonate should test at least 50 per cent. metallic copper. The effectiveness of the treatment depends on the uniform distribution of finely divided particles over the surface of the grain. One-half ounce per bushel has given nearly as good protection in spring seeding as 2 ozs. per bushel, while 2 ozs. per bushel of the Corona compound carrying only 18 per cent. copper has given nearly as good protection as 2 ozs. of the pure copper carbonate. Four ounces of the Corona compound per bushel gave perfect protection in spring wheat. Under field conditions giving a relatively low per cent of smut, 2 ozs. per bushel has given perfect protection while with conditions much more favorable for smut, 3 ozs. per bushel has produced a smut-free crop. Considering this fact, the use of 3 ozs. per bushel is worthy of trial for fall-seeded grain, where soil as well as seed-borne smut must be combatted. It may be noted that no harm will result from the use of all the copper carbonate that the seed will carry.

A word of caution may be offered against the possibility of too heavy seeding when using the carbonate treatment. The dry grain feeds faster through the drill than moist grain, the grains are not swollen and there is even an increased germination, hence the grower should set the drill to deliver less seed than has been customary with the old methods.

Since there have been some complaints of illness due to inhalation of copper carbonate dust while carrying out treating operations, farmers are urged to take proper protective measures. The following recommendations are offered: Use some form of respirator to prevent inhalation of dust especially if treating operations are to be carried out in a closed room. Dr. W. W. Mackie reports that the Willson Dustite Respirators made by the Willson Goggles Co., Reading, Pa., have been used with complete satisfaction in California, making it possible to work while enveloped in a cloud of the copper carbonate dust. If obliged to work without a respirator, treatments should be carried out in the open, and the apparatus should be so arranged that the wind will carry the dust away from the operator.

TABLE VIII.

Showing germination per cent of untreated and dusted seed of several varieties of wheat.

Date of Test	JENKINS CLUB		HYBRID 128		MARQUIS		IONES WINTER FIFE	
	Untreated	Treated with copper carbonate	Untreated	Treated with copper carbonate	Untreated	Treated with copper carbonate	Untreated	Treated with copper carbonate
February 7	85.	88.5	87.5	92.5	89.5	94.5	95.	90.5
March 8	67.5	90.	75.	60.	96.	85.	91.	96.
April 15	81.5	*	80.	*	84.	*	92.	*
May 8	76.	95.	79.5	89.5	77.	96.	84.	96.
June 24	77.	84.5	80.5	81.5	82.5	91.5	87.	92.
July 19	73.	84.5	83.5	91.	85.	91.5	91.5	94.5
August 22	79.5	78.	71.	87.5	82.	90.	78.5	91.
September 19	84.	83.5	84.	85.	84.5	85.	87.	92.
October 7	80.	81.5	82.5	80.	83.5	85.	82.	584.

TABLE IX.

Germination per cent of Fall-Seeded Wheat.

TREATMENT	Per Cent of Germination	
	HYBRID 128	TURKEY
Untreated seed	90.	95
Formaldehyde 1-30	36	45
Formaldehyde 1-50	63	70
Bluestone 1-5	40	52
Copper carbonate 2 oza. dust	90	95

Even if working in the open, the operator will find a respirator of value if treating grain continuously or for any extended period.

The application of the copper carbonate dust may be made in a number of different ways. In our earliest experimental work the treatment was carried out by shaking the seed and the requisite amount of copper carbonate in a closed container. A barrel churn has been used with good results, while in some larger operations a small concrete mixer has been tried. In some of the demonstration trials the dusting has been accomplished by emptying the wheat and the desired amount of copper carbonate on a canvas and shoveling over the mixture until the grain became thoroughly coated, but this last method is not recommended as it is felt that it gives the least effective distribution of the dust and offers more opportunity for persons doing the treating to inhale the irritating and poisonous dust particles. A special dusting machine has been designed which is effective and also convenient, and it is expected that this or similar machines will come into general use.*

Washington State College Smut-Treating Machine*

In designing a machine for the dry or dust treatment of wheat for smut the following points were kept in mind: (1) To handle the grain as little as possible; (2) To mix the grain and copper carbonate in sack lots; (3) To make the machine self-bagging; (4) To sack the grain in quantities that could easily be handled at the drill; (5) To mix the grain with as few turns of the drum as would give effective distribution; (6) To avoid the disagreeable copper carbonate dust; (7) To build a machine that a farmer having mechanical ability might make.

The accompanying illustration (Fig. 1) shows the principle of the mixer. The drum is revolved until the opening is under the filling hopper. A stop bolt through the vertical post holds the drum in filling position. The helper on the wagon then empties a sack of

*A recent letter from Dr. W. W. Mackie, Office of Cereal Investigation, Washington, D. C., who is stationed at the University of California, contains the following information: "We have perfected and patented an automatic dusting machine with a capacity of more than 300 bushels per hour. This machine takes the graded and cleaned wheat as it comes from the grader and cleaner and dusts it automatically in a confined space which does not permit the escape of dust."

grain into the hopper and it flows into the drum. (Fig. 2). The drum is then turned back so the operator standing on the ground can scatter the copper carbonate uniformly over the surface of the grain, after which the sliding door is put in position and the drum rotated for two minutes. This gives 20 to 30 revolutions per minute which is sufficient to coat thoroughly each grain with the powder.

In the drum there are three wooden radial mixers or buffers, of a width equal to half the radius of the drum (Figs. 1, 3). In position I the grain has slid off the board "b" and is being lifted by "a" during which time it flows over "a" like water over a dam. It should be

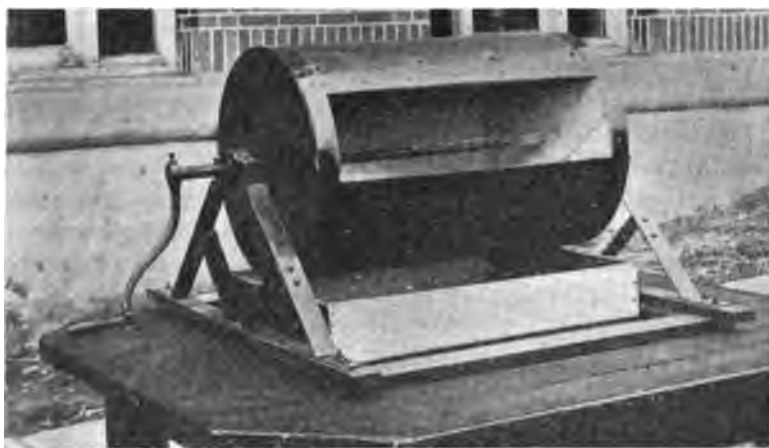


Fig. 5. View of the small dusting machine, which is arranged to empty into a box

noticed that the upper portion of the grain is passing over "a" first. Position II shows the bottom portion of the grain leaving "a" and forming the top of the pile below. Thus the grain is largely reversed in position each time it passes over a mixing-board, making three mixes per revolution of the drum. When the two-minute mixing period is completed, the drum is stopped at its filling position, and the sliding cover is pulled out. The drum is then turned one-half a revolution to position III at which position the treated grain is equally dumped into the two sacks below and is ready to be tied up for use in the field. (Fig. 4).

The ratio of the sprockets is 1 to 4, there being 6 teeth on the drive sprocket and 24 on the drum sprocket. The drum is 21 inches in diameter and 36 inches long. The machine stands five and one-half feet in height. The machine has a capacity of one full sack of wheat, but it is expected that partial sacks ($1\frac{1}{2}$ bushels) will be used. In treating a sack of wheat, the crank turns by hand about as hard as a cream separator. One sack can easily be run through every four or five minutes. It would therefore not take long to treat enough seed for a large field.

A blueprint showing all the dimensions of the smut-treating machine will be sent upon application, with a covering fee of twenty-five cents.

The first machine made to test the utility of this principle of mixing is shown in Fig. 5. The drum is 16 inches in diameter and 24 inches long. It was built as an investigational study in Agricultural Engineering by a student, Stephen White, whose ideas assisted very materially in the development of the larger machine. The small mixer will treat one-half bushel at a time. It is about as large as can be conveniently turned with the crank fastened to the axle of the drum, and would do very well for treating seed for small fields.

Advantages of the Copper Carbonate Treatment

The advantages of the dust treatment are so pronounced that this method of control may be expected to replace the older wet treatments with bluestone or formaldehyde. Even though it should give no better protection from smut, we should still continue to recommend it. It is our prophecy that we are now beginning the "copper carbonate period of seed disinfection." The important advantages of this copper carbonate dust may be briefly enumerated as follows:

1. The elimination of the inconvenient and disagreeable soaking methods.

2. The convenience of being able to treat seed days or even months before it is needed for use, thus making possible the utilization of spare time.

3. The elimination of seed injury and retarded growth, with even an improvement in germination over that of untreated seed. This will make possible a reduction in the amount of seed used per acre and should result in a considerable annual saving as soon as the method comes to be generally practiced.

4. The elimination of danger from seeding in the dry, making it possible to seed in the "dust," rather than being obliged to wait for rain.

5. Probable increased yields due to better stands, no retarding influence of the fungicide, and equal or better control of smut.

6. A probable increased protection from reinfection of treated seed by smutty sacks, broken smut balls or from the wind-borne spores that are generally present in our summer fallow fields.

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STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISION OF ENTOMOLOGY AND ZOOLOGY

The Orchard Leaf-Roller

By
Anthony Spuler



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MAR 22 '40

The Orchard Leaf-Roller

By

Anthony Spuler

Introduction

The orchard leaf-roller (*Archips argyrospila*) is quite generally distributed thruout the United States and parts of Canada. It first became known as a destructive pest in 1890 in Northern Colorado and is, therefore, sometimes known as the Colorado leaf-roller. Since then similar outbreaks have occurred in Oregon, California, Washington, Idaho, Montana, New Mexico, Missouri, New York, Maine and the Province of Ontario.

The leaf-roller has undoubtedly many natural enemies which tend to hold it in check. After serious outbreaks in other districts, parasites have established a natural control and reduced the leaf-roller to secondary importance. Whether this will hold true for the insect in the infested districts of Washington, Oregon, California, Idaho and Montana, where it is now prevalent, remains to be seen.

In the State of Washington the orchard leaf-roller was observed in the Spokane Valley as early as 1908. Previous to 1919, this insect was considered of minor importance, but during that year it began to increase with alarming rapidity in the Spokane Valley, especially the Greenacres-Otis Orchards district, and in the fall many egg-masses could be found. The following spring very little was done toward controlling this insect mainly because the weather was unfavorable for dormant spraying. As a result, the leaf-roller became very destructive in 1920, in some cases completely defoliating trees and destroying the entire crop. At the present time this insect is still considered the most serious insect pest in the Spokane Valley. It has spread over the entire valley and also is on the increase about Kettle Falls, thruout Spokane County, around Walla Walla, Kennewick, Yakima, Neppel, Wenatchee, Palouse and Pullman. Because of the increasing prevalence of the leaf-roller, this progress report is issued as an informational bulletin.

Life History of the Orchard Leaf-Roller

The orchard leaf-roller passes the winter in the egg stage. The eggs are deposited on the trunk, limbs, twigs and occasionally on the fruit, in gluey masses about one-eighth to one-fourth inch in diameter. These egg-masses are greenish at first, later changing to brown or pale brown, vary considerably in size and contain six to 115 eggs. The old hatched egg-masses may remain on the trees for a period of two years. By this time there is a marked breaking down of the individual egg-cells which is not found in the newly hatched egg-masses. It rarely happens that all of the eggs in an egg-mass hatch, even when not sprayed. Sometimes all of the eggs in a mass fail to hatch, which may be due to a lack of fertilization.

Early in the spring, about the time that the blossom buds begin

to show pink or even earlier, the eggs begin to hatch. The newly-hatched larvae are about one-sixteenth inch in length and greenish in color with the exception of the head and thoracic shield which are black. At this time they look for some tender morsel to eat and usually work their way into the blossom buds or into the blossoms after they have opened. Here they work beneath the stamen bars and often destroy the essential parts of the flower, before fertilization can take place. There is usually one larva to a blossom, altho there may be two or even more. Infested blossom buds are usually so badly spun with silken web that they are unable to open properly. The young larvae also attack newly developed leaves. After the second or third molt until mid-summer the larvae feed extensively on leaves and fruit, causing the leaves to roll up and become attached to the fruit. The caterpillars are very sensitive and have the habit of wriggling backward out of their webs when disturbed, but remain suspended by a silken web spun from the mouth. After swinging for a short time the caterpillars work their way back to the leaves or descend to the ground. Sometimes the wind will cause them to swing to a neighboring tree or shrub. About the middle of June the caterpillars become fully grown and are then a little less than an inch in length. They now spin themselves up in a silken web within curled leaves or within cavities eaten out of the fruit and pupate. In about two weeks the adult moths appear. The moths are scarcely a half-inch in length and vary in color from almost a sulphur yellow to yellow with brown mottlings. They remain in hiding during the day but become active at dusk and are more or less attracted by light. Egg laying commences a short time after the adults emerge. There is but a single brood a year.

Host Plants

The orchard leaf-roller is known to feed upon the following: Alfalfa, apple, apricot, cherry, currant, elm, gooseberry, locust, onion, pear, plum, poplar, prune, quince, raspberry and rose.

Nature of Injury

The first work of the larvae is upon the opening buds, blossoms, newly formed leaves and forming fruit, all of which may be partially or entirely destroyed. In cases of severe infestation, the trees may be entirely defoliated. Trees that are defoliated one year are in no condition to bear fruit the next. Fruit attacked when small develops into very irregular shapes (see figure on cover) and is unfit for market.

Control

Experiments on the control of the leaf-roller have been conducted along three definite lines: 1st, spraying with a heavy miscible oil to destroy the over-wintering eggs; 2nd, spraying with a contact insecticide to kill the young larvae (this also includes dusting); and, 3rd, spraying with an arsenical to poison the larvae when feeding.

Oil Spray—In the spring of 1921, on April 15, when entirely dormant, some trees on the Robinson place near Otis Orchards were heavily sprayed with various brands of miscible oil. On June 8, when all the viable eggs on the check tree had hatched, egg-masses removed from the trees were examined with a binocular microscope and the number of eggs hatched in each mass carefully noted. Following are the results obtained:

TABLE I.
Miscible Oil Treatments, 1921

Treatment	Hatched	Not Hatched	Total	% Not Hatched
Dormoil 12%	489	1886	2375	79.7
Dormoil 10%	1239	771	2010	38.3
Dormoil 8%	1359	630	1989	31.6
Spramulsion 12%	2294	298	2594	11.5
Spramulsion 10%	2057	198	2255	8.6
Scalecide 10%	880	1546	2426	67.1
Dormant Soluble Oil 10%.....	1330	851	2181	39.1
Dormant Soluble Oil 8%	1565	592	2157	27.5
Sulco 5%	1448	336	1784	18.9
Sulco 6%	1437	432	1869	23.8
Sol. Sul. and Dormoil 6%	1486	787	2273	34.5
Check	1879	155	2034	7.7

Judging from the foregoing table one would naturally conclude that a miscible oil was ineffective in controlling the leaf-roller. It must be remembered, however, that the spray was put on before material development had begun in the leaf-roller eggs. All insect eggs are generally considered to be much more resistant to sprays when completely dormant than when near the hatching period. In no case was there any evidence of oil injury to the trees.

In the spring of 1922 the experiment with the various oils was repeated on the Crawford place near Dishman. The sprays were applied April 24 and 25, at which time the tips of the leaves were in evidence. After the hatching was completed the egg-masses were removed as in the previous year and counts made of the number of eggs hatched. Following are the results obtained:

TABLE II.
Miscible Oil Treatments, 1922.

Treatment	Hatched	Not Hatched	Total	% Not Hatched
Ortho Oil 12%	463	1299	1762	73.8
*Ortho Oil 12%	1794	281	2075	26.4
Ortho Oil 8%	1107	384	1491	40.1
Scalecide 10%	187	1362	1549	87.9
†Scalecide 10%	379	1611	1990	81.
Scalecide 8%	220	1270	1490	85.3
Spramulsion 10%	334	1096	1430	76.7
†Spramulsion 12%	458	1296	1754	74.
Dormoil 10%	151	1689	1840	91.8
†Dormoil 10%	251	1609	1860	86.5
Dormoil 8%	387	1070	1457	73.5
†Dormoil 8%	504	1275	1779	70.5
Dormant Soluble Oil 10%	145	1856	2001	92.8
Dormant Soluble Oil 8%	465	1429	1894	76.6
Dormant Soluble Oil 7%	389	1330	1699	78.3
Check	1432	313	1745	18.

Judging from the results obtained from the foregoing table, a 10 per cent strength of either Dormant Soluble Oil or Dormoil of 1922 composition gave fairly good control. Had the spraying been

delayed for a few days a weaker strength would probably have been equally effective. The Ortho oil did not emulsify well and formed into droplets when applied to the trees. It is interesting to note in this connection that a rain coming after the spray has had a chance to dry is not so great a factor in destroying the value of the spray as has commonly been supposed.

A great deal has been said in recent years about oil injury to trees. Much of this complaint can justly be laid to winter injury. Oil sprays are generally considered to have a stimulating effect on tree growth. It is probable that the oil has a dissolving effect on the wax of the bark, thus allowing earlier and increased respiration to take place. Gillette and Weldon[‡] of Colorado and Penny^{||} and Jones[°] of California have observed that trees sprayed with oil have a greener and more thrifty appearance. This stimulating effect has also been noticed in the State of Washington. Investigations in the use of oil sprays, conducted over a period of fifteen years by the Division of Entomology of the Washington Experiment Station, in connection with its work on the San Jose scale and lately on leaf-roller, show not a single case of oil injury. Reports from Colorado, Oregon and California show similar results. On the other hand, Parker[‡] of Montana reports considerable injury to trees from the use of oil sprays. In summing up these investigations one is led to believe that oil sprays, where properly emulsified and not used in excessive strengths, are safe in moderate climates. In other words oil injury is closely related to extreme low temperatures over a period of time. Just what effect an oil spray has on trees sprayed after a period of extreme cold is not definitely understood. According to Dr. F. L. Pickett, Professor of Botany at the States College of Washington, there is a rapid drying out of the wood of twigs during a period of extreme cold and this drying out process probably renders the wood less impervious to the penetrating qualities of the oil. Oils which penetrate are generally thought to destroy the living cells. Dr. Felt, State Entomologist of New York, is also of the opinion that oil injury at this time is due to the fact that oil penetrates the tissues of sap wood. This same penetrating action of the oil is supposed to take place if the trees are sprayed immediately before a severe freeze. Of recent years, the winters of 1919-20 and 1921-22 have been unusually severe when the temperature dropped considerably below zero, and remained there for a long period. Almost all of the complaints of oil injury have followed in the wake of these two severe seasons. In the Bitter Root Valley of Montana, the winter temperatures are normally quite low and injury from oil sprays is quite common. In California, where winter temperatures are considerably higher, winter spray injury from the use of dormant oil sprays is unknown. Properly used oil sprays should, apparently, not be regarded as dangerous unless excessively cold weather precedes or follows the spraying. In order to reduce danger from oil injury, sprays of this kind should not be applied in the fall of the year or in the spring until after danger of severe freezing has past.

Another objection to oil sprays is their variable composition. Many of the so-called miscible oils now on the market have the same

*Hail and rain fell within one-half hour after trees were sprayed and at a time when trees were still wet with spray.

‡Hail and rain seven hours after spray had dried on trees.

§Circular 5, Office of State Ent., Col., Oct. 1912.

°Jour. Economics Entomology 14 (1921) pp. 428-33.

‡Rept. Wash. Hort. Assoc., 1914, p. 159.

‡Better Fruit, XVI, March, 1922, p. 9.

physical composition as far as the fruit grower can determine, yet there is a tremendous difference in their insecticidal value. Unfortunately, some of the oils sold under a well-known trade name have given good results one year and poor results the next. Unfortunately also there is no standard way of testing the insecticidal value of a miscible oil. About the only way that this could be done would be to test out the oils on leaf-roller eggs incubated in an insectary some time during the winter. However, oils that have a heavy body and emulsify well have usually given good results.

Summer Contact Sprays—Experiments conducted in 1920 with nicotine sulphate showed very poor results. Investigations immediately after the application of nicotine sulfate showed a number of larvae completely stupified so that they appeared dead. After a few hours many revived and seemed none the worse for their experience. In the spring of 1922 samples of Derrisine products were distributed by Messrs. McDougall & Robertson, Ltd., Manchester, England, and ground tobacco stems, fortified with nicotine, by the Hall Tobacco Chemical Company, St. Louis. It was hoped that these new products might give some good results on the leaf-roller. On May 19 and 20 these materials, together with a dust known as Callispray No. 1 from the California Sprayer Company, and nicotine sulfate alone were tried out on a row of trees in the Crawford orchard near Dishman. At this time the larvae were very small and were usually found in the blossoms. An American Beauty duster, also furnished by the California Sprayer Company, was used. The dust was applied very liberally, yet the following day a number of blossoms which showed the characteristic webbing of the leaf-roller, gave the following results:

TABLE III.
Contact Sprays for Young Larvae.

Treatment	Dead	Alive	Miss'g	Total	%Alive
Tobacco dust 3½%	10	32	9	51	62.7
Tobacco dust 2½%	15	75	16	106	70.8
Callispray No. 1	25	74	14	113	65.5
Derrisine 1-800 and Soap	13	93	12	118	79.8
Derrisine 1-800 and Casein	28	165	23	216	87.
Derrisine 1-400 and Soap	16	84	13	113	74.3
Nicotine Sulfate 1-800 and Soap	9	71	12	92	77.
Nicotine Sulfate 1-400 and Soap	12	77	15	104	74.
Nico Dust 3½% and Corona Dry					
Lead, 1 lb. 6 oz. to 120 oz.	6	110	12	128	85.9
Check	0	105	15	120	87.3
*Lead Arsenate, 3 lbs.-100 gal.	4	41	9	54	75.7

Upon examining the blossoms that showed characteristic webbing it was found that in many instances the larvae had disappeared. Whether they had been overcome by fumes and had dropped to the ground or had simply left to feed elsewhere could not be determined. In all cases of this kind the larvae were reported missing. It will be noted that all of the contact sprays gave uniformly poor results.

*Adjacent trees sprayed by owner shortly after the leaf-roller caterpillars had hatched. Counts made two days after spraying.

A second application of the same materials was made June 13. At this time the larvae were fully grown and quite resistant. The results obtained were even less encouraging than those obtained in the May application. The powdered tobacco stems, although very irritating to the operator, seemed to have little or no effect on the full-grown larvae, other than to stupefy them for a short time, even when they were rolled in the dust. A dust made of hydrated lime and nicotine sulfate was much more effective. Larvae rolled in this dust were immediately overcome and did not recover. It is possible that a dust with a higher nicotine content might give considerably better results, but the cost would interfere with its general acceptance. Of the liquid sprays neither the nicotine sulfate nor the Derrisine can be considered to hold any promise of giving control.

Lead Arsenate Sprays—The leaf-roller caterpillars seem to be remarkably resistant to arsenical sprays. Whether this is actually true or whether the spray acts as a repellent to the caterpillar to such an extent that it will not eat it or that it rejects it after biting into it, is a point to be determined. It is certainly true that the ordinary treatment for codling moth has little effect on the leaf-roller. Fruit growers who have used Paris green at the rate of six pounds to 100 gallons have had only partial success. This amount of Paris green is equivalent to eight pounds of lead arsenate to 100 gallons. It seems, therefore, that failure to control the leaf-roller with an arsenical spray is not because of an insufficient amount of poison.

Based on the idea that the arsenical spray might act as repellents and that a small dosage if eaten would be as effective as a stronger one, the following experiment was conducted in the R. M. Hanson orchard near Dishman. Three rows of twenty-six trees each were selected. The first was sprayed with lead arsenate at the rate of four pounds to 200 gallons; the second with the same amount of lead to which ten quarts of corn syrup had been added; the third with lead arsenate used at eight pounds to 200 gallons. The purpose of the syrup was to overcome the repellent nature of the lead arsenate. Unfortunately the sprays were not applied before the calyx spraying for the codling moth had been given. The leaf-roller nests examined within a few days and again in a week after the spraying was completed showed the following results:

TABLE IV.
Arsenical Treatments for Young Leaf-Rollers

Treatment	Alive	Dead	Miss'g	Total
Lead Arsenate 1-50	65	0	53	118
Lead Arsenate 1-50 and Syrup 2½ qts...	37	3	36	76
Lead Arsenate 2-50	32	4	35	71

Since it was difficult to determine what happened to the larvae that had left the rolled-up leaf, this method of checking was considered inconclusive. At harvest time the fruit from all of the trees in each row was carefully examined and all leaf-roller injury noted. The results were as follows:

TABLE V.
Leaf-Roller Injury to Apples

Treatment	Apples Examined	Apples Sound	Apples Injured	% Injured
Lead Arsenate 1-50	5833	5176	657	11.2
Lead Arsenate 1-50 and Syrup 10 qts. to 200 gals.	5827	5264	563	10.7
Lead Arsenate 2-50	5865	5421	444	8.2
Check	314	267	47	15.0

These counts show that the addition of syrup added very little to the efficiency of the spray. Doubling the dosage gave slightly better results, but it is doubtful whether the added 3 per cent of sound fruit would pay for the increased cost of the lead arsenate.

Conclusions

1. Based on our present state of knowledge, the best treatment for the leaf-roller is as follows:

a. Spraying with a reliable miscible oil just before the hatching period of the eggs.

b. In cases of severe infestations this spray should be supplemented by an arsenical spray, applied as soon as the eggs have hatched.

2. The use of lead arsenate in excess of 2 pounds to 50 gallons or the addition of syrup does not materially add to the efficiency of the spray.

3. Miscible oil sprays when properly emulsified are considered safe to apple trees unless the spraying is preceded or followed by excessively cold weather arbitrarily suggesting 20 degrees below zero as minimum temperature.

4. Nicotine dust and liquid sprays of nicotine sulfate or Derrisine have given no practical control.

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STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISION OF
FARM MANAGEMENT

The Cost of Producing Milk, and Dairy Farm Organization in Western Washington

By
GEORGE SEVERANCE
AND
ERNEST R. JOHNSON

BULLETIN NO. 173
November 1922

**All Bulletins of this Station are Sent Free to Citizens of the State on
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*In co-operation with the United States Department of Agriculture

**In co-operation with Chelan County and dairy farm Organizations.

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The Cost of Producing Milk and Dairy Farm Organization in Western Washington

INTRODUCTION

Probably in no line of agricultural production has more intense feeling developed from time to time between producers, distributors and consumers than in connection with the production and distribution of dairy products. Long and bitter controversies over the price of milk have occurred in many parts of the United States. One of the greatest handicaps in the satisfactory settlement of these controversies has almost invariably been the lack of definite accurate information regarding the cost of producing milk. In recognition of this need, together with the fact that dairying is one of the most important agricultural industries in Washington, the Experiment Station made this study of the cost of milk production for Western Washington for the two years 1919-1920. Similar studies have been or are being made in many leading dairy sections of the United States by the various State Experiment Stations and the U. S. Department of Agriculture. It is believed that wherever these studies are sufficiently extensive to overshadow seasonal, local or individual irregularities, a formula showing the average basic requirements of feed and labor for producing milk expressed in terms of quantities rather than price may be established that will serve as a reasonably safe guide in all such controversies. At any given time, current prices may be applied to such formulae to determine the approximate average cost of producing any considerable supply of milk.

Another important purpose of such investigations is to show the consumer what enters into the cost of producing milk. The consuming public is quite fair-minded and usually willing to pay the producer cost of production and a fair living when it can learn with reasonable accuracy what is the cost. A wide-spread dissem-

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ination of accurate information regarding the cost of production would do much to eliminate much of the misunderstanding that now exists.

Probably the most valuable indirect benefit of cost of production studies results from analyzing the records of individual farms to discover any strong features of management that may be adopted by others or to detect weak features of management that may be avoided. The cost of producing milk on the farms included in this investigation in 1919 varied from \$1.94 per 100 pounds on the best managed farm to \$4.39 on the most poorly managed farm. In 1920, the cost varied from \$1.81 to \$4.56 per 100 pounds of milk. In every dairy community there are some dairymen who are able to produce milk for less than half what it costs some others largely because of better management. No producer should expect the public to cover the cost of gross mismanagement. The producer who is running behind may derive much profit from studying the results of any investigation that will help to show where he may improve his methods of management. Even the operator who produces milk for less than the average cost will usually discover by a careful study of the management of other farms some superior features of management that he may introduce to further reduce his cost of production. In fact, there are very few who manage so well that they cannot find some one who excels them in some one feature of management.

General Plan of Investigation

Since there were several cow testing associations in operation in Western Washington during the period of this investigation, keeping an accurate record of the production of each cow both of milk and of butterfat and reasonably accurate records of the feed and pasture consumed by estimates carefully made each month, it was decided to limit the investigation to members of cow testing associations where conditions of production fairly represent the average in Western Washington. Arrangements were made to cooperate with Cow Testing Associations in Whatcom County, Snohomish County, Wahkiakum County and Pacific County. Farms were selected that were operated primarily as dairy farms and that were operated under normal conditions. An investigator visited each dairy with a complete set of blank forms and secured all the data necessary to

supplement the association records for determining the cost of production. In the fall of 1920, records of the preceding year's business were secured from 91 dairy farms maintaining 1502 cows which produced 10,148,381 pounds of milk. In the fall of 1921, records were secured from 81 dairy farms maintaining 1469 cows which produced 10,341,074 pounds of milk. These two years' records form the basis of this investigation.

The period covered in the 1919 survey was January 1 to December 31 for 29 farms in Whatcom County and 20 farms in Snohomish County; May 1, 1919 to April 30, 1920 for 12 farms and August 1, 1918 to July 31, 1919 for 21 farms in Pacific County; and July 1, 1918 to June 30, 1919 for 9 farms in Wahkiakum County.

The period covered in the 1920 survey was the same as in 1919 for 22 farms in Whatcom County and 27 farms in Snohomish County; October 1, 1920 to Sept. 30, 1921 for 5 farms in Snohomish County; August 1, 1920 to July 31, 1921 for 14 farms in Pacific County; and Jan. 1, 1920 to Dec. 31, 1920 for 13 farms in Wahkiakum County.

Areas Studied

The farms studied were located principally in the river valleys or adjoining uplands in Whatcom, Snohomish, Wahkiakum and Pacific Counties. In all sections studied the farms produce heavy yields of forage and are devoted very largely to maintaining the dairy herds, almost exclusively so in Wahkiakum and Pacific Counties where transportation of salable crops is more difficult, the rainfall more abundant and the pasture season somewhat longer than in Snohomish and Whatcom Counties. Table I shows the average size of farms, the tillable area, and the character of the pasture land on the farms studied in each county.

- (1) **Total Area** means the entire area operated by one dairyman.
- (2) **Tillable Area** means the number of acres that can be plowed and cultivated.
- (3) **Woods** refers to the number of acres in woods that furnished some pasture to the cows.
- (4) **Stump Land** pasture is land that had been slashed and burned and provided pasture for the milking herd.

Table I
Average Size of Farms, Tillable Area and Distribution of Pasture in Each County. Average for Two Years.

Location of Association	Average Number Acres per Farm						Total Number Acres Used for Pasture
	Farm Area Total Area (1)	Tillable Area (2)	Woods (3)	Pasture Area Stump Land (4)	Rotation (5)	Cropped (6)	
Whatcom Co.	109	68	2	15	15	23	55
Snohomish Co.	136	44	2	23	12	9	46
*Pacific Co. (Willapa Valley)	113	48		28	15	14	57
Pacific Co. (S. W. Wash. Ass'n.)	124	29	16	24	7	13	60
Wahkiakum Co.	121	44	4	20	15	16	55

* for 1919 only.

(5) **Rotation Pasture** is tilled land that is used entirely by the milking herd for pasture one or more years during a rotation.

(6) **Cropped pasture** is land that has grown a crop (i. e. clover, oats, etc.) and then is used to furnish pasture for the cows.

Description of Herds

Table II shows the number of herds and the number of cows in each group studied for 1919 and 1920.

The breeds and the quality of the cows varied somewhat with the location of the Association, the kind of product sold and with the importance of the dairy industry in the community. Table III which shows the average quantity of milk and butterfat produced per cow in each of the counties will also throw some light upon the quality and the breed of cows predominating in each particular area. The cows in Whatcom and Snohomish counties led the other groups in milk production. This was due largely to the predominance of Holsteins and Guernseys and to a more intensive type of dairying which was made possible by better established markets for their products. Most of the dairymen in the Whatcom, Snohomish and Willapa Valley Associations (Willapa Valley records for 1919 only) disposed of their dairy products in the form of market milk, while the dairymen in the other associations (southwestern Washington and Wahkiakum County) were obliged to sell cream to local cooperative creameries or to points on the Columbia River in Oregon. Nearly all of the cows in the cream shipping areas were grade or high grade Jerseys and Guernseys. This was especially true in the Wahkiakum Association where an unusually intensive type of cream production has been developed. The cream was entirely sold to the local cooperative creameries, each dairyman delivering his own cream to the market. Referring again to Table III it will be noticed that although the Wahkiakum cows averaged 536 pounds less than the Snohomish cows in milk production, their average butterfat production was 22 pounds more; which, of course, was due largely to the predominance of Jerseys as compared with Holsteins in Snohomish county.

In 1919, the average inventory values of the cows in the different associations were as follows: Whatcom, \$130; Snohomish, \$123; Wahkiakum, \$126 and Pacific, \$100. For 1920 the average

Table II
 Number of Herds, Number of Cows in Each Group Studied and Average Size of Herd for Two Years.

	Whatcom		Snohomish		Pacific		Wahkiakum	
	No. Herds	No. Cows	No. Herds	No. Cows	No. Herds	No. Cows	No. Herds	No. Cows
1919	29	495	20	375	33	449	9	183
1920	22	394	32	665	14	171	13	249
Total No. Herd Records	*51		52		47		22	
Total No. Cow Records		889		1030		620		432
Average Size of Herd		18		20		13		20

*Some of the 29 herds visited in 1919 were visited again in 1920 so that while 51 represents the total number of full years' records secured in two seasons the exact number of individual herds visited is somewhat less than 51. The same is true for each of the other counties.

Table III
 Average Quantity of Milk and Butterfat Produced Per Cow in Each of the Four Counties.

Year	Whatcom			Snohomish			Pacific			Wahkiakum		
	Milk lbs.	Butter Fat %	lbs.	Milk lbs.	Butter Fat %	lbs.	Milk lbs.	Butter Fat %	lbs.	Milk lbs.	Butter Fat %	lbs.
1919	7530	4.42	233	6647	4.51	300	6132	4.04	248	6619	5.11	328
1920	8355	4.28	358	7082	4.17	295	5004	5.09	255	6237	5.11	310
Average	7942	4.35	345	6864	4.34	297	5568	4.57	251	6328	5.11	319

was about \$10 less for each county except Pacific where the average was about \$20 less due to the fact that the higher valued cows in the Willapa Valley Association were not included in the 1920 inventory for Pacific County.

Basis Used in Determining Cost of Production

There are three different bases used by different investigators in determining the cost of producing milk.

First—The Farm Basis. Where almost the entire farm income is secured from dairy products, every expense incurred in operating the entire farm is assumed to be an expense of operating the dairy and all receipts other than for milk and its products including all crops sold are subtracted from the gross cost of operating the farm to determine the net cost of producing milk. This basis is satisfactory where everything is concentrated upon milk production but the milk produced on such highly specialized dairy farms forms so small a percentage of the total production that the "Farm Basis" is impractical.

Second—The Herd Basis. Some investigators assume that the primary purpose of maintaining a dairy herd is for the production of milk. Under this assumption all the expense incurred in maintaining dairy stock of all ages is treated as an expense of producing milk and all receipts other than from the sale of milk and its products including receipts from sale of young stock are subtracted from the gross cost of operating the herd to determine the net cost of producing milk. The production of crops is treated as an independent business, all farm feed being charged to the dairy at its market value on the farm, those crops having no established market, like silage or roots, being charged at their feeding value as determined by comparison with salable products. This basis of determining the cost of milk production is satisfactory where the herd is maintained solely for the production of milk, but so large a percentage of the country's milk supply is produced on farms where the receipts from milk and its products do not constitute more than half or two-thirds the total dairy receipts that this basis is not applicable widely enough to justify its use. In cases where the production of stock proves particularly profitable, the cost of producing milk might be reduced to a very low point or even be eliminated by treating the receipts from livestock as milk production receipts.

Third—The Cow Basis. Under this basis the producing herd, consisting of all mature cows and the herd sire, are considered the unit. A heifer is charged to the producing herd as soon as she drops her first calf and all costs incurred in her maintenance thereafter until she dies or is sold, whether producing or dry, are charged to milk production. Every product of the farm used by the producing herd is charged to milk production at its market value at the farm, regardless of what it may have cost to produce it. The value of calves at birth is credited to milk production, since the maintenance of the dam during pregnancy and the sire has been charged to milk production, but the development of the young animals after birth is considered a separate business. This method of determining the cost of milk production is the most generally applicable and is the one followed in this investigation.

Factors of Cost

The various items entering into the cost of producing milk have been assembled under certain heads designated "Factors of Cost" and are treated in the following paragraphs.

Feed. An estimate and record of the feed consumed by each cow was made each month by the cow tester with the aid of the dairymen. Purchased feed was charged at the purchase price plus cost of delivery. Home grown feeds were charged at their farm value (market value less cost of hauling to town.) Pasture values were computed on the basis of what it would cost to rent pastures in the locality. In some sections the cows run out practically the entire year, but the pasture charge includes only those months in which the cows secure an appreciable amount of feed. The pasture charge corresponds quite closely to a five per cent interest charge on the land used for pasture only. Table IV shows the average values of feed and pasture for different counties as used in this investigation.

The grain ration was practically all purchased and consisted quite generally of bran, mill run or shorts supplemented by home grown oats and peas in Snohomish and Whatcom Counties. A few dairymen used a small amount of patent dairy feeds, oil meal, corn meal and molasses. The average cost of the grain ration per ton for the different counties varied from \$44.05 to \$51.14 in 1919, and from \$51.80 to \$56.20 in 1920. This variation was due largely to the variation in relative amounts of cheaper or of higher priced feeds which

Table IV
Average Value of Feed Per Ton and of Pasture Used for Each County

	Whatcom				Snohomish				Pacific				Wahkiakum			
	1919	1920	Aver.	1919	1920	Aver.	1919	1920	Aver.	1919	1920	Aver.	1919	1920	Aver.	Aver.
Grain	\$44.05	\$56.20	\$50.12	\$51.14	\$51.80	\$51.47	\$47.68	\$52.40	\$50.04	\$50.12	\$55.60	\$52.86				
Hay	20.92	20.60	20.76	23.60	22.40	23.00	22.80	20.20	21.50	20.45	20.80	20.62				
Silage	7.90	9.80	8.85	8.27	8.78	8.52	7.90	7.98	7.94	7.00	9.12	8.06				
Roots & Kale	8.67	9.56	9.12	12.57*	6.62	9.34	8.92	7.50	8.21	6.00	8.46	7.20				
Pasture Rate																
per Mo.	3.72	3.15	3.43	4.34**	3.87**	4.10	2.59	2.04	2.29	3.73	3.51	3.62				
No. Months																
Pasture	6.30	6.80	6.50	6.90	6.70	6.80	8.00	8.60	8.30	7.00	7.40	7.20				

* Includes potatoes

** includes soiling

composed the ration. About three-fourths of the total hay consumed by all cows was home grown and consisted principally of clover and grasses. The Snohomish County farms purchased the greatest amount of hay although some hay was purchased in each of the other counties. The purchased hay consisted almost entirely of alfalfa imported from irrigated districts. Home grown hay was estimated at from \$18 to \$28 per ton while purchased hay ranged from \$20 to \$40 per ton, only a small percentage of the hay being valued at the higher rates as the average in Table IV would indicate. As shown in Table VII, the average feed cost per cow for the two years in each of the four counties varied from \$73.30 in Pacific County to \$116.17 in Whatcom County.

It will be noted in Table VIII, that Pacific County has the longest pasture season and uses the smallest quantity of concentrates. This is due to greater rainfall, a longer growing season and a less intensive type of dairying which results partly from greater inaccessibility. It will also be noted under Pacific County in the same table that there was a considerable dropping off in the amount of grain, hay and succulents consumed the second year and a considerable increase in the pasture season. This is explained by the fact that the first year's investigation included the Willapa Valley Association, where dairying was more specialized. These dairy farms sold milk entirely, had higher producing cows and more hay, grain and succulents, but had a much shorter pasture season than the members of the Southwestern Washington Association. The abundance of cheap pasture in the small river valleys and on tide lands in the area of the latter association did much to reduce the annual feed cost per cow. As previously stated, the members of the Southwestern Washington Association, due to poorer marketing facilities, were compelled to sell cream. Returns from marketing cream under conditions existing in this area could not begin to compare with the profits made in the districts where market milk could be sold. Hence these dairymen apparently were not encouraged to increase their average production per cow by heavier feeding of grain and hay, which accounts largely for the comparatively poor production per cow in this area. As will be seen by the average test (Table III), Jerseys and Guernseys predominated in the Southwestern Washington Association while in the Willapa Valley Association and in the other associations where milk was sold almost entirely, the Holstein breed predominated.

Wahkiakum County shows a greater feed consumption per cow (Table VIII) in 1920 than in 1919, but about a one-half month shorter pasture season, which is largely accounted for by the poorer pasture season in 1920, and an effort to maintain the production by heavier feeding. Similar reasons will account for the annual variation in the amount of feed and pasture consumed by the Whatcom and Snohomish County herds.

Bedding. Many farms use only the residue from hay or other roughage to bed the cows, in which case no separate charge has been made for bedding. Some dairies buy sawdust and others buy straw for bedding which is charged to milk production at cost. Where by-products of the farm are used they are charged at what they would sell for on the farm if salable. The separate charge for bedding as shown in Table V was comparatively small and varied from \$.03 per cow in Wahkiakum County to \$3.44 per cow in Whatcom County.

Labor. The labor organization on the western Washington dairy farms varied somewhat, depending upon the size of the dairy herds and the degree of specialization practiced. On the smaller and on the less specialized dairy farms, the work is done to a large extent as chores by members of the family who spend a large portion of the day caring for crops. On the larger and on the more specialized dairy farms, the dairy work constitutes full-time work for one or more men. In this investigation, the amount of work devoted to the dairy was carefully estimated by the farmer. Since the amount of time devoted to the dairy day by day is quite regular, it is believed that these estimates are quite reliable, particularly on the more specialized farms.

Hired labor was charged at cost while family labor was computed at the normal rate paid for such labor, including board, which was \$100 per month or thirty-three and one third cents per hour in 1919 and thirty cents in 1920. Labor done by children was charged at what it would have cost to do the same work with mature men.

Table VIII shows the number of hours of man labor required per cow and per 100 pounds of milk to produce milk and deliver it to the marketing or transportation point in each of the four counties. It will be noted that the Snohomish and the Whatcom County herds show an increased labor cost per cow of thirteen and eleven hours respectively in 1920 compared with 1919, yet the increase in the

average production per cow (Table III) was sufficient to reduce slightly the number of hours of labor required to produce 100 pounds of milk. The comparatively large amount of man labor required to produce 100 pounds of milk in Pacific County, especially the second year, was due to the large amount of time spent in delivering the cream to the marketing point and to a poorer average production per cow. The same was true to a large extent in Wabkiakum County.

Horse labor was charged directly against milk production at twenty cents per hour in 1919 and fifteen cents per hour in 1920 when horses were used directly in the production of milk, e. g., hauling milk or cream to the collecting stand, the creamery or other initial collecting point. Home grown feeds were charged to the cows delivered in the barn and manure was credited to the cows at the barn, so the amount of direct horse labor charged, as shown in Table V, was very low varying from an average of \$.20 per cow in Snohomish County to \$1.51 per cow in Wahkiakum County.

The Sire. In dairies where sires were kept, the charge for sire service includes seven per cent interest on a fair inventory value of the sire, depreciation, feed, labor, equipment used in his care, shelter, taxes, veterinary service and registration fees, less credits received from outside service and manure. Very little revenue was derived from outside sire service, however, since nearly all the dairymen in the localities studied kept their own sires. Any decrease in the sire inventory at the end of the year became the charge for depreciation, while if the final inventory showed an increase, the sire enterprise was credited with the amount of the appreciation. The average cost of sire service in each area is shown in Table V. On the individual farms where sires were kept, the cost of sire service varied from \$2.27 to \$23.82 per cow.

Building Service. The cost of building service is probably the most difficult of all to determine accurately because the buildings vary so widely in size, construction and condition; the cost of construction is known in so few cases, and they are used for such a variety of purposes in many cases. The use of all buildings and paddocks that contributed to the operation of the dairy, including silos, milk houses and manure sheds, was included in the cost of building service and charged against milk production. The portion to charge against the cows was determined by pro-rating the annual cost of each

building according to the number of animal units served. One cow, one horse, or two head of young stock were considered an animal unit. The annual cost of buildings includes depreciation, six per cent interest on the inventory value, taxes, insurance and repairs. Depreciation was determined by dividing the inventory value of each building by the estimated number of years it would last. Taxes and insurance were based on the rates used in the locality. The barnyard or paddock charge includes six per cent interest on the estimated value of the area plus taxes. The charge per cow for the use of buildings varied on individual farms from \$3.74 to \$27.11. Table V shows the two-year average charge for the use of buildings for each area studied.

Equipment. The charge for the use of equipment includes seven per cent interest on the inventory value and depreciation and repairs on all equipment that contributed directly to the production and preparation of milk and butterfat for market, including milk pans, pails, strainers, cooler, separator, milking machine, engine for separator or milking machine, wagon or special conveyance for hauling milk or cream, scales, feed grinder, barn tools and veterinary instruments. Depreciation was determined for each important piece of equipment by dividing its inventory value by the estimated number of years it would last. The repair charge was what the dairyman actually paid out during the year. Table V shows that in the two-year average the charge for the use of equipment varied from \$2.47 per cow in Snohomish County to \$4.29 in Wahkiakum County.

Current Expenses. This heading includes all miscellaneous expenditures on the milking herd not otherwise classified, veterinary fees and medicine, breeding fees, cow testing fees, board of cow testers, disinfectants, electric light and power, gasoline for dairy engines and whitewashing. The exact cost of these various items was used wherever the data were available and in other cases was estimated as accurately as possible. The average charge for current expenses in each area is shown in Table V.

The Herd. For purposes of this investigation, all mature cows were considered a part of the herd from the time they first came into production until they were sold or died, whether raised or purchased. If raised on the place, they were charged to the herd at a fair valuation at the time of dropping their first calf. If purchased, they

were charged to the herd at purchase price. However, if calves or growing helpers were purchased, they were treated like calves born on the place and charged to the herd upon dropping their first calf. After they were introduced into the herd, all expenses incurred in their maintenance thereafter, whether milking or dry, were charged to milk production.

The "herd cost" includes interest, taxes and depreciation. Practically none of the farmers carried insurance, so this item was omitted. Seven per cent interest was charged on the inventory value of the cows. Taxes varied somewhat with the locality and were compiled at the current rates from data furnished by the assessors of the four counties. Taxes averaged about one and one half per cent on the full valuation.

If the inventory value of the cows in a given herd at the end of the year, plus receipts from cows sold during the year, was less than the inventory value at the beginning of the year plus the value of the cows purchased and helpers introduced during the year, the difference was considered the depreciation charge for the herd. If greater, the difference was included under "Credits Other than Milk" as "Appreciation." As nearly as possible, the year-end inventories were made to show the actual decrease or increase in producing value, assuming the cattle market to remain the same. The depreciation includes losses by death, decrease in the value of cows still retained, and losses due to selling cows for beef at less than their inventory value at the beginning of the year. The "Interest and Taxes" and "Depreciation" on cows may be found in Table V.

Cash Marketing Costs. A large proportion of the milk and cream was collected on milk routes at from ten cents to thirty-five cents per 100 pounds of milk and from one to two cents per pound for butter fat. The cash marketing cost, as shown in Table V, represents the actual amount of cash the dairyman paid for getting his product to the market. The cost per 100 pounds of milk was obtained by dividing the total amount thus paid by all dairymen included in this investigation by the total hundred-weight of milk produced. The cost per cow was obtained by dividing the total cash thus paid by the total number of cows on all farms studied.

If the dairyman delivered his products direct to the market or to the assembling point, it was considered a non-cash cost and

taken care of by the labor charged to milk production. The majority of the farms studied in Pacific and Wahkiakum Counties were not served by a milk route and, therefore, were required to deliver their own products to the local creamery or to the marketing point.

Use of Car. When an automobile was used to deliver the milk, haul feed or in any other way to serve the dairy, an estimate was made as to the extent to which it was used for dairy purposes. The average charge per cow and per 100 pounds of milk for use of car, shown in Table V, was obtained by dividing the total charged for use of car on all farms studied by the total number of cows kept and the total hundred-weight of milk produced respectively.

Credits Other Than Milk

The gross cost of producing milk was reduced somewhat by the following credits other than milk, as shown in Table V.

Manure. Manure recovered at the barn, as estimated by the farmer, was credited to the dairy in all cases at \$1.50 per ton in 1919 and \$1.00 per ton in 1920. It was believed that these rates represented a fair value for the manure utilized with average intelligence for the production of crops on a dairy farm. A failure of the farmer to utilize the manure with average intelligence after the cows have produced it is believed to be no fault of the dairy nor is the gain secured by occasional exceptional uses of the manure believed to be properly credited to milk production.

Calves. Calves were credited to the dairy at what they would bring at four days of age on the basis of grade stock, whether sold or retained, such value ranging from \$1 to \$5 each.

Hides. Cow and calf hides were credited to the dairy at what they brought.

Sacks. In some cases sacks accumulate in considerable numbers where feed is purchased and these were credited to the dairy at their market value as second-hand sacks.

Appreciation. Whenever the inventory value of all the cows in a herd on hand at the end of the year, plus the receipts from the sale of cows during the year, exceeded the value of the cows on hand at

the beginning of the year plus the value of cows purchased and heifers introduced into the herd during the year, the difference was included in "Credits other than milk" as "Appreciation."

Gross and Net Cost of Producing Milk

The sum of all the cost factors constitutes the gross cost of producing milk or the "total operating cost" and is shown for each county studied and for all counties averaged together in Table V. The "Total Operating Cost" minus the "Total Credits Other than Milk" leaves the "Net Cost of Production," as shown in the last two lines of Table V.

It will be seen that the final average net cost of 100 pounds of milk for the two years for all counties studied was \$2.84 and that the county averages do not vary markedly from the general average, the greatest departure from the general average being sixteen cents per 100 pounds of milk in Wahkiakum County, while two counties, Whatcom and Pacific, vary only three cents from the general average. Table VI shows the per cent of the total cost represented by each item of cost, as shown in Table V, for each county, and for all counties averaged together for the two years. All costs are grouped into feed, labor and other costs in Table VII. It will be noticed that although the relative proportion of grain, silage and pasture vary considerably in different counties, as shown in Table V, the percentage of total cost represented by feed in each case runs fairly uniform, as shown in Section B, Table VII; the average for all counties being 47.34 per cent of the net cost. As might be expected, the feed represents a lower percentage of the total cost in Pacific and Wahkiakum counties than in Snohomish and Whatcom counties, due partly, to the longer pasture season and partly to a less intensive type of dairying practiced where the dairymen are forced to sell cream to creameries. It will be noted on the last line of the table that when the cost of feed and labor is combined it represents 75.52 per cent of the net cost when all counties are averaged, and that the several counties vary only slightly from the general average. This would seem to indicate that in any of the localities studied or in localities where conditions are similar, the cost of feed and labor could be assumed to represent three-fourths of the net cost with reasonable accuracy.

Table V

Summary of Costs and Credits Other than Milk Per Cow and Per 100 lbs. Milk (Av. 1919-1920)

Items of Cost	Whatcom			Snohomish			Pacific			Wahkiakum			Weighted Avg.		
	Per Cow	Per 100	Per Year	Per Cow	Per 100	Per Year	Per Cow	Per 100	Per Year	Per Cow	Per 100	Per Year	Per Cow	Per 100	Per Year
Feed Grain	\$46.33	\$58.02	\$28.02	\$23.52	\$40.80	\$14.47	\$26.09	\$25.35	\$40.21	\$31.78	\$44.63	\$28.61	\$31.78	\$44.63	\$28.61
Hay	30.14	.3840	23.52	.3412	.2860	33.64	.5976	22.38	.3456	28.61	.4148	12.44	28.61	.4148	12.44
Silage	15.50	.1927	19.53	.55	.0070	3.92	.0697	3.98	.0631	12.44	.1803	1.46	12.44	.1803	1.46
Roots and Kale	1.98	.0250	.55	.0070	.0070	2.02	.0357	1.39	.0220	1.46	.0213	24.51	1.46	.0213	24.51
Pasture and Soiling	22.22	.2816	28.21	1.73	.0253	19.25	.3465	27.96	.4412	24.51	.3554	1.89	24.51	.3554	1.89
Bedding	3.44	.0436	1.73	.0253	.7281	.88	.0286	.03	.0008	1.89	.0275	49.77	1.89	.0275	49.77
Labor—Man	52.55	.6636	49.91	.20	.0025	47.25	.8549	46.60	.7366	49.77	.7219	.70	49.77	.7219	.70
—Horse	30	.0035	.20	.0025	.0025	1.38	.0237	1.51	.0231	.70	.0100	8.17	.70	.0100	8.17
Use of Sire	9.49	.1186	7.63	.1114	.1114	7.95	.1236	7.63	.1204	8.17	.1185	10.85	8.17	.1185	10.85
Use of Building	10.88	.1381	11.82	.1739	.1739	9.47	.1639	10.72	.1691	10.85	.1573	3.12	10.85	.1573	3.12
Use of Equipment	3.42	.0437	2.47	.0360	.0360	3.04	.0551	4.29	.0676	3.12	.0453	7.19	3.12	.0453	7.19
Current Expenses	8.48	.1070	7.90	.1153	.1153	5.52	.1005	5.50	.0867	7.19	.1041	7.22	7.19	.1041	7.22
Interest—Taxes	10.85	.1374	10.09	.1471	.1471	7.98	.1444	9.34	.1474	9.79	.1420	7.22	9.79	.1420	7.22
Depreciation	9.82	.1241	7.07	.1023	.1023	3.75	.0695	7.09	.1117	7.22	.1048	2.77	7.22	.1048	2.77
Marketing (Cash)	6.86	.0860	11.19	.1618	.1618	5.57	.1018	.06	.0020	7.33	.1063	2.77	7.33	.1063	2.77
Use of Car	1.88	.0225	2.98	.0434	.0434	1.76	.0311	5.33	.0844	2.77	.0400	207.00	2.77	.0400	207.00
Total Cost	234.14	2.95	212.82	3.10	3.10	167.85	3.01	179.16	2.82	207.00	2.9959	207.00	207.00	2.9959	207.00

Table V—Cont.

Credits Other Than Milk	Per Cow		Per 100		Per Cow		Per 100		Per Cow		Per 100		Per Cow		Per 100		Per Cow		Per 100	
	Per Year	lbs. Milk	Per Year	lbs. Milk	Per Year	lbs. Milk	Per Year	lbs. Milk	Per Year	lbs. Milk	Per Year	lbs. Milk	Per Year	lbs. Milk	Per Year	lbs. Milk	Per Year	lbs. Milk	Per Year	lbs. Milk
Manure	\$ 6.61	.0844	\$ 5.55	.0814	\$ 6.58	.1157	\$ 5.34	.0842	\$ 6.17	.0894										
Calves	2.95	.0363	3.28	.0480	3.00	.0538	2.63	.0416	3.02	.0438										
Hides	.10	.0012	.07	.0009	.05	.0007	...	...	.07	.0010										
Sacks	.65	.0086	.53	.0078	.67	.0119	.60	.0091	.60	.0087										
Appreciation	.36	.0043	.20	.0028	.78	.0134	.32	.0052	.41	.0060										
Total Credits Other than Milk	10.67	.1358	9.63	.1409	11.08	.1955	8.89	.1401	10.27	.1489										
Total Cost	234.14	2.95	212.82	3.10	167.85	3.01	179.16	2.82	207.00	2.99										
Total Credits Other than Milk	10.67	.1358	9.63	.1409	11.08	.1955	8.89	.1401	10.27	.1489										
Net Cost of Producing Milk	223.47	2.81	203.19	2.96	156.77	2.81	170.27	2.68	196.73	2.84										
Net Cost Per lb. of Producing Butter Fat		\$.647		\$.715		\$.623		\$.534												

Table VI

Relation of Each Item of Cost and of Credits to Total Cost Expressed in Percentage.
Average for Two Years.

Items of Cost	Whatcom	Snohomish	Pacific	Wahkiakum	Weighted Avg.
Feed—Grain	19.76%	13.17%	8.31%	14.08%	14.90%
Hay	12.93	11.07	19.86	12.44	13.85
Silage	6.55	9.16	2.31	2.27	6.02
Roots and Kale	.86	.25	1.19	.77	.71
Pasture and Solling	9.52	13.28	11.53	15.63	11.86
Bedding	1.48	.82	.48	.03	.92
Labor—Man	22.46	23.45	28.46	25.98	24.10
Labor—Horse	.13	.09	.79	.86	.33
Use of Bull	4.02	3.58	4.74	4.28	3.95
Use of Building	4.66	5.54	5.59	5.97	5.25
Use of Equipment	1.46	1.16	1.83	2.40	1.51
Current Expenses	3.62	3.70	3.35	3.06	3.47
Interest and Taxes	4.64	4.75	4.79	5.23	4.74
Depreciation	4.20	3.32	2.36	4.00	3.50
Marketing (Cash)	2.92	5.26	3.37	.06	3.55
Use of Car	.79	1.40	1.04	2.94	1.34
	100.00	100.00	100.00	100.00	100.00
Relation of Credits Other Than Milk to Total Cost..	4.55%	4.52%	6.49%	4.97%	4.97%

Table VII
Summary of Feed, Man Labor and Other Costs Per Cow and Per 100 pounds Milk
Average for Two Years.

(A) Expressed in Money Value

	Whatcom		Snohomish		Pacific		Wahkiakum		Weighted Avg.	
	Per Cow	Per 100 lbs. Milk	Per Cow	Per 100 lbs. Milk	Per Cow	Per 100 lbs. Milk	Per Cow	Per 100 lbs. Milk	Per Cow	Per 100 lbs. Milk
Feed	\$116.17	\$ 1.463	\$ 99.83	\$1.454	\$ 73.30	\$1.311	\$ 81.00	\$1.274	\$ 98.80	\$1.4181
Man Labor	52.55	.664	49.91	.728	47.25	.855	46.60	.734	49.77	.722
Other Costs	65.42	.826	63.08	.919	47.30	.847	51.40	.813	58.43	.856
Total Costs	234.14	2.95	212.82	3.10	167.85	3.01	179.16	2.82	207.00	2.996
Net Cost	223.47	2.81	203.19	2.96	156.77	2.81	170.27	2.68	196.73	2.84

(B) Expressed in Per Cent.

	% of		% of		% of		% of		% of	
	Total Cost	Net Cost	Total Cost	Net Cost	Total Cost	Net Cost	Total Cost	Net Cost	Total Cost	Net Cost
Feed	49.62	51.99	49.93	49.14	43.20	46.76	45.19	47.61	47.34	50.22
Man Labor	22.46	23.52	23.45	24.57	28.46	30.14	25.98	27.39	24.10	25.30
Other Costs	27.92		29.62		28.34		28.83		28.56	
Feed and Labor Costs	72.08	75.51	70.38	73.71	71.66	76.90	71.17	75.00	71.44	75.52

Basic Cost Formula

In order to make it possible to compute the probable cost of producing milk at any given time, Table VIII is arranged to show the amount of feed and labor required per cow per annum and per 100 pounds of milk for each county and for all counties averaged. It will be noted that the amounts of given ingredients vary when different counties and different years are compared with the general average but, as shown in Table VII, the aggregate cost for feed and labor approximates very closely 75 per cent of the net cost in each case. It will be seen from inspection of the column showing the weighted average cost per hundred weight of producing milk that it requires 17.7 lbs. of grain, 38.2 lbs. of hay, 47.1 lbs. of succulents, 3.1 days of pasture and 2.3 hours of man labor to produce 100 lbs. of milk.

To illustrate how the formula may be used, let us assume that at a given time grain is worth \$25 per ton, hay \$15 per ton, succulents \$5 per ton, pasture \$.10 per day, man labor \$.25 per hour.

Using these prices, the problem would be solved as follows:

17.7 lbs. grain @ \$25 per ton	\$.22
38.2 lbs. hay @ \$15 per ton	.29
47.1 lbs. succulents @ \$5 per ton	.12
3.1 days pasture @ \$.10 per day	.31
2.3 hrs. of labor @ \$.25 per hr.	.58
Total for feed and labor	\$1.52

\$1.52 divided by .7552 equals \$2.01, the approximate average cost of producing 100 pounds of milk under price conditions stated.

It must be borne in mind that this basic formula is an average for the production of a considerable quantity of milk and is believed to be approximately correct only when applied to the production of a considerable number of herds maintained under conditions similar to those prevailing in the dairy sections included in this study. The price would be too high when applied to the more successful dairies and too low when applied to the unsuccessful ones but should approximate the average cost for an entire district very closely. It should be noted also that to apply at any given time and place with reasonable accuracy the relative price of the various cost factors should bear the same relation to each other that they do in this

Table VIII
Feed, Pasture, and Labor Requirements Per Cow and Per 100 Pounds of Milk

	Whatcom		Snohomish		Pacific		Wahkiakum		Weighted Aves. for 2 years	
	Per Cow Per Year	Per 100 lbs. Milk	Per Cow Per Year	Per 100 lbs. Milk	Per Cow Per Year	Per 100 lbs. Milk	Per Cow Per Year	Per 100 lbs. Milk	Per Cow Per Year	Per 100 lbs. Milk
Grain (lbs.)	1919....	1780	23.7	1075	868	14.2	823	12.9		
	1920....	1897	22.7	1101	315	6.3	1081	17.4		
	Average....	1839	23.2	1088	592	10.2	952	15.2	1218	17.7
Hay (lbs.)	1919....	3385	45.0	1739	26.2	57.5	1866	29.0		
	1920....	2400	29.0	2353	33.8	53.5	2463	39.5		
	Average....	2893	37.0	2046	30.0	55.5	2165	34.2	2630	38.2
Succulents (inc. roots, silage and kale) (lbs.)	1919....	2949	43.4	5597	84.2	28.9	1362	21.3		
	1920....	4432	53.1	3915	55.5	23.6	1469	23.5		
	Average....	3690	48.3	4756	69.9	27.3	1416	22.4	3246	47.1
Pasture and Solling (Days)	1919....	191.1	2.5	207.8	3.0	3.9	237	3.7		
	1920....	197.4	2.4	202.5	2.9	5.1	224	3.6		
	Average....	194.3	2.4	205.1	2.9	4.5	231	3.6	214	3.1
Man Labor (Hrs.)	1919....	161	2.14	153	2.30	2.40	135	2.11		
	1920....	174	2.08	164	2.30	3.06	162	2.59		
	Average....	167.5	2.11	158.5	2.30	2.73	148.5	2.35	158	2.30

Table IX

Comparison of Feed and Labor Requirements on Farms Selling Milk and Farms Selling Cream.

1919

	Requirements On Farms Selling Milk			Requirements On Farms Selling Cream		
	Per Cow Per Year	Per 100 lbs. Milk	Per lb. B. F.	Per Cow Per Year	Per 100 lbs. Milk	Per lb. B. F.
Grain (lbs.)	1353	18.8	4.4	1024	16.7	3.62
Hay (lbs.)	3109	43.1	10.0	2452	40.0	8.66
Succulents (lbs.) (inc. Silage, Roots, and Kale)	3974	55.1	12.8	2074	33.9	7.32
Pasture (days)	201	2.8	.65	233	3.8	.84
Man Labor (hours)	158	2.19	.51	142	2.31	.50
% Net Cost rep. by Feed and Man Labor.....	75.46	75.46	75.46	75.94	75.94	75.94

1920

	Requirements On Farms Selling Milk			Requirements On Farms Selling Cream		
	Per Cow Per Year	Per 100 lbs. Milk	Per lb. B. F.	Per Cow Per Year	Per 100 lbs. Milk	Per lb. B. F.
Grain (lbs.)	1378	17.9	4.4	985	16.2	3.4
Hay (lbs.)	2345	31.5	7.4	2540	42.0	8.6
Succulents (lbs.) (inc. Silage, Roots, and Kale)	4306	56.0	13.6	1851	30.5	6.4
Pasture (days)	200	2.6	.63	298	4.9	1.0
Man Labor (hours)	167	2.18	.53	162	2.67	.54
% Net Cost rep. by Feed and Man Labor.....	71.45	71.45	71.45	75.85	75.85	75.85

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Table IX—Cont.

Average—1919-1920

	Per Cow Per Year	Per 100 lbs. Milk	Per lb. B. F.	Per Cow Per Year	Per 100 lbs. Milk	Per lb. B. F.
Grain (lbs.)	1365	18.3	4.4	1004	16.4	3.51
Hay (lbs.)	2727	37.3	8.7	2496	41.0	8.63
Succulents (lbs.) (inc. Silage, Roots, and Kale) .	4140	55.5	13.2	1962	32.1	6.86
Pasture (days)	200	2.7	.64	265	4.3	.92
Man Labor (hours)	162	2.18	.52	152	2.49	.52
% Net Cost rep. by						
Feed and Man Labor....	73.46	73.46	73.46	75.89	75.89	75.89

study. The percentage of the net cost represented by feed and labor, 75.52, would not be correct if the price of one or more of the essential factors of cost should rise or fall much more in proportion than the prices of the other factors.

In Table IX the same data are tabulated to show the quantities of the ingredients required per cow per year for the production of 100 pounds of milk and for the production of one pound of butter fat on farms selling milk and on farms selling cream. It is interesting to note that, with the exception of the farms selling milk in the year 1920, the total feed and labor cost represent slightly over 75% of the net cost in each case.

Table X shows the average production of milk and butter fat per cow each year on farms selling milk and on farms selling cream; It will be noted that the average production on farms selling milk was considerably higher than on farms selling cream. This is the normal situation, the whole milk business usually resulting in a somewhat more intensive type of dairying than the production of cream for creameries. Although feed and labor constitute practically the same percentage of the net cost in each case, the higher values for both feed and labor that prevail in the more intensive dairy sections will result in a higher net cost of production in applying the formula, which is the result that should be expected.

Table X

Average Production Per Cow Per Year on Farms Selling Milk and on Farms Selling Cream.

	Farms Selling Milk		Farms Selling Cream	
	Milk lbs.	But. Fat lbs.	Milk lbs.	But. Fat lbs.
1919	7209	310	6040	279
1920	7701	318	6047	296
Average	7455	314	6043	287

Chart I is a graphic representation of the distribution of costs.

Production, Costs and Profits

Dairymen are concerned with profits in the final analysis. Table IX is arranged to show the value of product, the net cost per cow, the price paid per pound of butter fat and the profit per cow for each county each year studied. It will be noted that the average profits per cow were fair in all counties studied except Pacific County,

GRAPHIC REPRESENTATION OF DISTRIBUTION OF COSTS ON PERCENTAGE BASIS



WHATCOM



SNOHOMISH



PACIFIC



WAHIAKUM



COMPOSITE

where there was a loss of \$1.00 per cow in 1919 in the district selling whole milk and a loss of \$14 per cow in 1919 in the district selling cream. It is only fair to state that in 1919, the producers of whole milk were forced to buy considerably more hay than usual and were obliged to sell much of their whole milk to a cheese factory at considerably less than the normal price for milk. In 1920, the year covered in this study ended later in this area than in any other area studied and included a period of very low prices, which brought the average down to forty-nine cents per pound for butterfat or considerably less than that received in any other district. This low price is doubtless one of the causes for the average loss of \$14 per head in the district that showed an average profit of \$28 per head in 1919.

A tabulation of all the individual herds in all the counties studied, which is too voluminous to print in this bulletin, shows eighteen herds producing at a profit and four herds producing at a loss in Whatcom County; five herds producing at a profit and nine herds producing at a loss in Pacific County; thirteen herds producing at a profit and nineteen herds producing at a loss in Snohomish County; and thirteen herds producing at a profit and no herds producing at a loss in Wahkiakum County.

Many are puzzled to know why so many dairymen produce at a loss or for such low profits and still continue to follow dairying. The fact is that in many cases the labor is performed largely, if not entirely, by the family and the property contributing to the production of milk is clear of indebtedness in whole or in part so that a large part of the expense that correctly enters into the cost of production is not actually paid out by the dairyman.

To illustrate—suppose a dairyman has \$10,000 invested in his farm and dairy. The family do work worth \$1,500 at current rates. In calculating the results of his dairy operations the business is charged with \$1,500 for labor and \$600 interest on the \$10,000 investment. The complete calculations show a loss of \$500 in the operation of the dairy. Not paying out any money for labor performed by his family or any interest on the money he has invested, the dairyman has \$1,500 plus \$600, or \$2,100, with which to cover the \$500 loss, pay the living expenses of his family and add to his savings. Although in this case the family would lack \$500 of receiving as much as though they worked out for regular wages and loaned

Table XI
Average Value of Product, Costs and Profits Per Cow and Average Price Per Pound Butterfat Received in Each of
the Four Counties.

Year	Whatcom				Snohomish				Pacific				Wahkiakum			
	Average per Cow		Price		Average per Cow		Price		Average per Cow		Price		Average per Cow		Price	
	Value of Prod.	Net Cost	Profit	per lb. butterfat*	Value of Prod.	Net Cost	Profit	per lb. butterfat*	Value of Prod.	Net Cost	Profit	per lb. butterfat*	Value of Prod.	Net Cost	Profit	per lb. butterfat*
1919	\$246	\$218	\$28	.74	\$232	\$204	\$28	.78	(1) \$219 (2) \$167 (2) \$125	\$220	\$— 1 28 —14	\$.78 .73 .49	\$220	\$165	\$55	.67
1920	234	229	25	.71	216	203	13	.73		139			198	176	22	.64

* On farms selling cream, skim milk was given credit of \$.25 per pound in 1919 and \$.20 per pound in 1920 and entered as a receipt in figuring the profit or loss per cow.

The value of skim milk was not deducted in figuring the cost of producing 100 pounds of milk or butterfat on farms shipping cream.

(1) Willapa Valley (for 1919 only).

(2) S. W. Washington Cow Testing Association.

their money at 6% interest, it is not uncommon to find families that will live with such frugality under such circumstances that they are actually able to lay up a little money each year. This does not indicate that the cost of producing milk has been figured too high, but it does show the dogged determination to succeed that is possessed by some families.

Variations in Net Cost

Table XII shows the volume of milk produced at different net costs per 100 pounds of milk in all counties studied. Chart II is a graphic representation of the same information.

Table XII
Volume of Milk Produced at Different Net Costs Per 100 lbs. of Milk in All Counties Studied.

1919					
Cost	Groups	Average Cost	Quantity Produced	Per Cent of Total	Cumulative Per Cent
Below	\$2.00	\$1.94	116,931 lbs.	1.15%	1.15%
\$2.01	2.20	2.08	565,484 lbs.	5.57	6.72
2.21	2.40	2.32	792,162 lbs.	7.80	14.52
2.41	2.60	2.53	2,286,421 lbs.	22.54	37.06
2.61	2.80	2.72	1,493,055 lbs.	14.72	51.76
2.81	3.00	2.92	1,569,500 lbs.	15.47	67.35
3.01	3.20	3.12	849,164 lbs.	8.28	75.53
3.21	3.40	3.29	979,089 lbs.	9.65	85.18
3.41	3.60	3.48	670,859 lbs.	6.61	91.79
3.61	3.80	3.64	69,828 lbs.	.68	92.47
3.81	4.00	3.88	427,657 lbs.	4.21	96.68
4.01	4.20	4.09	233,671 lbs.	2.30	98.98
4.21	4.40	4.39	103,560 lbs.	1.02	100.00
4.41	4.60				
1920					
Cost	Groups	Average Cost	Quantity Produced	Per Cent of Total	Cumulative Per Cent
Below	\$2.00	\$1.84	342,490 lbs.	3.31%	3.31%
\$2.00	2.20	2.10	937,294 lbs.	9.06	12.37
2.21	2.40	2.34	1,156,933 lbs.	11.19	23.56
2.41	2.60	2.45	1,313,596 lbs.	12.70	36.26
2.61	2.80	2.73	1,714,351 lbs.	16.58	52.84
2.81	3.00	2.87	1,432,736 lbs.	13.86	66.70
3.01	3.20	3.09	1,440,089 lbs.	13.93	80.63
3.21	3.40	3.30	1,088,874 lbs.	10.53	91.16
3.41	3.60	3.44	337,068 lbs.	3.26	94.42
3.61	3.80	3.70	121,483 lbs.	1.17	95.59
3.81	4.00	3.85	98,049 lbs.	.95	96.54
4.01	4.20	4.30	358,111 lbs.	3.46	100.00

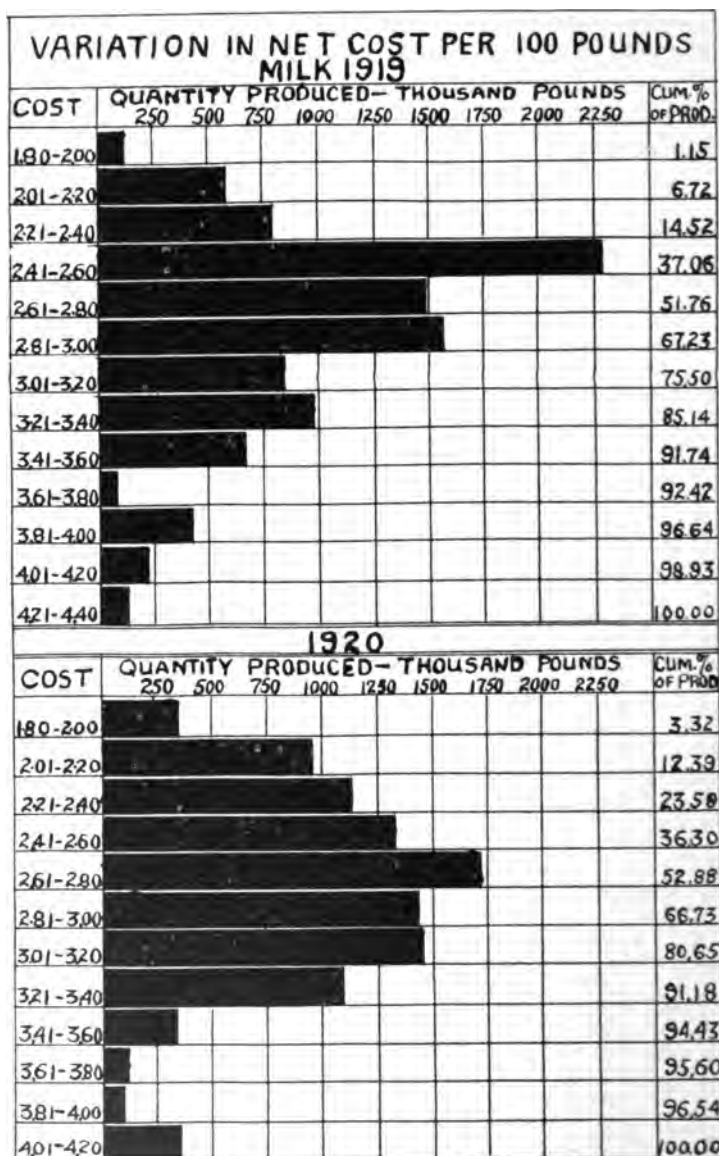


CHART TWO

In this chart the farms were grouped according to net costs, as shown in the column of costs at the left side of the chart. The shaded bars represent the relative amounts of milk produced at various costs. The column of percentages at the right shows the total percentage of the whole output that was produced at or below each successive cost in the scale of costs. The outstanding fact shown by this chart is that while the large bulk of the milk is produced within a reasonably narrow range of costs, there is a wide range of costs both above and below the costs of the main bulk of the milk. Although those dairymen who have reduced the cost of production markedly below the general average may have been helped to some extent by unusually favorable circumstances, it is safe to say that such reduction is due in large part to better management. At least some of the features of this better management could be adopted by other dairymen to advantage. There are quite a number of producers whose costs are so far above the general bulk that unless they can improve their management very markedly, it would be better for them to quit the dairy business.

From the standpoint of the public, it should be appreciated that although it would be entirely unjust to ask the consumer to pay a price that would cover the cost of production on the farms under poorest management, it is quite necessary to pay a price somewhat above the average cost of production in order to encourage the production of enough milk to supply the country's needs. Just where this line should be drawn no one is able to say. Some investigators have suggested that this line, termed the "bulk costs line," should be drawn so that eighty-five per cent of the milk supply would be produced at or below the proposed price, leaving the most expensive fifteen per cent to be produced at a loss.

The equitable adjustment of prices between producer and consumer through the operation of natural economic laws is made difficult, in so far as it affects those whose business is primarily dairying, by the fact that a vast amount of the country's dairy products is produced as by-products on farms where waste or cheap feed is utilized and where the dairy offers a means of cashing in on more or less idle time of children or over-time of men and women. Such farmers will continue to produce when the prices drop very low for the sake of realizing even a small return for their more or less unsalable

feed and surplus time. This situation retards the return of prices to the point where the commercial dairyman can recover the cost of feed and labor for which he must figure full value, working a great hardship at times on those whose chief source of income is the dairy.

SOME WAYS BY WHICH NET COSTS MAY BE DECREASED

Improving Quality of Stock. In order to show the relation between production and costs, the herds studied in Whatcom and Snohomish Counties in 1919 and 1920 have been grouped in Table XIII according to average production per cow per herd. It will be seen that the cost per cow both for feed and for other costs is higher in every case with each successive increase in production but that the average cost per pound of butterfat decreases progressively with each successive increase in production. This table shows the value of better producing cows and also shows that the increased production and reduced net cost calls for more expense per cow.

To make further study of the relation of production to cost, the 25 of the herds grouped in Table XIII that produced at least cost and the 25 herds that produced at greatest cost were grouped into two divisions in Table XIV. The tabulation shows that the best herds produced 8516 pounds of milk per cow per year, containing 478 pounds of butterfat, at a net cost of \$207.32; while the poorest herds produced 5879 pounds of milk per cow per year, containing 277 pounds of butterfat, at a net cost of \$224.28. It is thus seen that through the use of the good herds 478 pounds of butterfat were produced for \$16.96 less (\$224.28-\$207.32) than it cost to produce 277 pounds of butterfat through the use of the poorest herds. Of course, there are other features of management that exerted an influence, as further inspection of the table will show, but the high production is the outstanding feature of the most economical herds.

To be very profitable a cow must possess the capacity to consume a considerable quantity of feed in excess of maintenance requirements and convert it into milk. Innumerable cow testing association records show that cows vary markedly in this respect. Cows that have proved, under good feeding and care, that they do not possess this capacity to a sufficient degree to cover the cost of production, including interest on investment, should be sold, not to some

Table XIII
Relation of Average Butter Fat Production Per Herd and the Cost Per Cow to the Cost
Per Pound of Butter Fat, Based on Data From 103 Complete Yearly Herd Records
From Whatcom and Snohomish County Farms in 1919-1920.

Production Groups	No. Herds	No. Cows	Average Production Per Cow Per Year	Average Cost Per Cow Per Year			Average Cost Per lb. Butter Fat
				Feed Cost	Other Costs	Total Cost	
Average Production of Butter Fat Per Cow Per Year							
250 lbs. or less	13	227	224	\$ 92	\$103	\$195	\$.87
251—300	24	457	278	101	107	208	.75
301—350	39	735	338	112	112	224	.68
351—400	21	411	379	118	122	240	.63
Over 400	6	89	440	141	127	268	.61

Table XIV

A Comparison of Twenty-five Herds Producing Milk at Least Cost with Twenty-five Herds Producing Milk at Greatest Cost in Whatcom and Snohomish Counties.

Average No. Cows Per Herd	Twenty-five Herds Producing Milk at Least Cost			Twenty-five Herds Producing Milk at Greatest Cost		
	19.0	Butterfat	14.5			
	Milk	478 pounds	Milk	5879 pounds	277 pounds	Butterfat
Avg. Production Per Herd	8516 pounds					
Items of Cost	Per Year	Total Cost	Per Year	Total Cost	Per Year	Total Cost
	Cost Per Cow	Per Cent of	Cost Per Cow	Per Cent of	Cost Per Cow	Per Cent of
Food—Grain	\$38.28	17.66%	\$31.57	13.48%		
Hay	28.89	13.32	31.09	13.27		
Silage	12.69	5.86	18.52	7.90		
Roots & Kale	1.02	.47	.71	.30		
Pasture & Solling ..	23.22	10.71	24.39	10.41		
Bedding	1.65	.76	2.43	1.04		
Labor—Man	48.37	22.31	58.10	24.80		
Labor—Horse	.23	.11	.79	.34		
Use of Bull	7.65	3.55	11.14	4.76		
Use of Equipment ..	2.44	1.13	3.71	1.59		
Use of Building	9.31	4.30	15.10	6.45		
Current Expenses	7.23	3.34	8.42	3.59		
Interest & Taxes (cows) ..	10.91	5.03	9.73	4.16		
Depreciation	8.40	3.87	10.23	4.27		
Marketing (Cash)	14.08	6.49	6.34	2.71		
Use of Car	2.35	1.09	1.94	.83		
Total Cost	\$216.72	100.00%	\$234.21	100.00%		
Credits Other Than Milk ..	9.40	4.33	9.93	4.24		
Net Cost	\$207.32	95.67	\$224.28	95.76		

other dairyman but to the butcher. Unfortunately, the heavier producing cows are largely picked up by dairymen who sell whole milk, many of whom raise no calves but depend upon keeping up their herds by purchase. The poorer grade of cows, on the other hand, tend to gravitate to the less intensive dairy sections where skim milk is kept at home and the heifers are raised both to replenish the home herd and for sale. Thus there is the average tendency to lose the breeding service of the best female stock and to multiply the poorer grade of stock. There should be some cooperative effort to save heifers from the best cows where whole milk is sold.

Probably the greatest room for improvement in the productive capacity of stock is through the fuller use of the very best sires. In 1919, 53 sires were maintained to serve 1502 cows, when by proper cooperation, such as is practiced in the modern bull associations, fifteen to twenty well-selected bulls would have been sufficient. If proper discrimination were practiced in the use of bulls the better half of these cows, which would probably include all from which it would pay to save heifers, could be served by seven to ten high-class sires. Bull associations are still further enlarging the usefulness of the best sires by moving them to other associations as soon as their daughters in one association are ready to breed.

Table XV shows the profit that would result from displacing herds with given performance with higher producing herds. It will be seen that Group 1 produced 224 pounds of butterfat at a cost of \$195; while Group 2, the next highest producing group, produced the same amount of butterfat for \$168, a saving of \$27. Group 3, a still higher producing group, produced 224 pounds of butterfat for \$152, or a saving of \$43 as compared with the cost of producing the same amount of butterfat with Group 1.

By studying the table it will be seen that the decrease in the cost of butterfat and the saving in the cost of production per cow were much greater in the step from the poor herd to the herd of fair quality than in the step from the fairly efficient herd to the exceptional herd, the first reduction being twelve cents per pound, the second reduction seven cents per pound, the third reduction five cents per pound and the fourth reduction two cents per pound of butterfat. Thus from the standpoint of economic milk production, it appears that the first step in building up a poor herd (replacing

Table XV

Yearly Savings in Cost of Producing Butterfat that Might Be Effected by Displacing Herds of Given Capacity with Higher Yielding Herds, Computed from Table XIII.

Group No.	Classification of Herds Group Performance lbs. B. F.	Av. Prod Per Cow Per Year	Cost Per Lb. B. F.	Cost of Prod. 224 lbs. B. F.	Saving in Cost of Prod. 224 lbs. B. F. by Disp. Group 1 with Successive Groups	Cost of Prod. 278 lbs. B. F.	Sav. in Cost of Prod. 278 lbs. B. F. by Disp. Group 2 with Successive Groups	Cost of Prod. 338 lbs. B. F.	Sav. in Cost of Prod. 338 lbs. B. F. by Disp. Group 3 with Successive Groups.	Cost of Prod. 379 lbs. B. F.	Sav. in Cost of Prod. 379 lbs. B. F. by Disp. Group 4 with Successive Groups.
1	250 lbs or less	224 lbs.	\$.87	\$195							
2	251—300 lbs.	278 lbs.	\$.75	\$168	\$27	\$208	\$19	\$224	\$16	\$240	
3	301—350 lbs.	338 lbs.	\$.68	\$152	\$43	\$189	\$33	\$208	\$23	\$232	
4	351—400 lbs.	379 lbs.	\$.63	\$141	\$54	\$175	\$39	\$201			\$8
5	401 and above	440 lbs.	\$.61	\$137	\$58	\$169					

scrubs with grades) is not only the easiest step to accomplish but is the one that promises the largest return for a given expenditure of money and labor.

Probably in no other phase of dairy management is there so great room for increasing profit as there is in improving the producing capacity of the stock. Extra food and labor is wasted if applied to animals that do not possess the capacity to respond to the better care.

Better Feeding. Table XIV shows that while the best herds produced 478 pounds of butterfat for \$16.96 less net cost than was required to produce 277 pounds of butterfat with the poorer herds, the better herds were actually fed about one-fifth more grain per head, thus placing the expense where it would count most in producing milk. The two big factors in securing production are productive cows and ample feed, (including water). Further inspection of the table will show that much of the extra expense of the "high cost" herds was applied to items that have very little influence on production.

Table XIII also shows that the cost of feed has increased with increase in production more rapidly than the increase in other costs, but that the cost per 100 pounds of milk and per pound of butterfat has decreased with each increase in feed and production.

A common mistake is to permit cows in full flow to run down in flow and in physical condition during a shortage of pasture or frequently when the feed supply is low just before the pasture season opens. In such cases the loss is not confined to the period of short feed, for the cows seldom can be brought back to their full flow when they are later placed on full feed and much of the feed must be used to bring them back into proper physical condition. Sometimes the dairyman's affairs are in such shape that he is forced to keep his cows on short feed at such times and suffer the consequences, but as a rule such situations occur quite regularly at certain rather definite seasons and can be provided for by planning in advance and properly proportioning the season's forage crops so as to provide the proper amount of feed for the periods of shortage. Some provide succulents for the dry summer pasture period by putting up additional silage. Others seed the necessary acreage of grain, vetch or other annual crop that will be ready to feed off during

the summer drought. It frequently pays to feed purchased feed at a loss during such periods in order to keep the cows in condition to utilize feed to advantage when the period of cheaper and more abundant feed arrives.

When the supply of important feed like silage is limited and there is no chance to secure more, it is better to plan the feeding so that it will be distributed over the period during which it is really needed. It is not uncommon for dairymen to start feeding liberally from such feed supply without any thought of the end, only to find that the supply is exhausted long before the end of the period.

Another common mistake in feeding is to confine the cows to too limited variety of feeds to avoid the purchase of any outside feed. This may often pay when the outside feed costs too much more than home grown feeds, but as a rule it is best to provide a fairly well-balanced ration. Many dairymen in certain parts of Washington are found confining their cows very largely to timothy hay, grain or wild hay as roughage, or confining them to oats for grain. For cows to do best it is necessary that the cured roughage consist very largely of legume hays, and if the home-grown non-leguminous hay is of good market quality it would usually be better to sell some and buy some legume hay to feed in its stead. Standard grain feeds run so nearly together in price that it seldom pays to confine cows to a single home-grown grain. Some dairymen fail to provide any form of succulence or provide for only part of the year. Succulence in some form is one of the most essential factors in economic milk production and should be provided in some form throughout the year. Many make the mistake of feeding too light, giving the cows very little more than a maintenance ration. It is impossible for cows to do their best unless they are given as much in excess of the maintenance ration as they are capable of consuming and converting into milk economically. Feeding beyond their capacity results in waste. The exact point at which a cow will do her best is an individual matter and must be determined by varying each cow's feed and watching results carefully. The majority of dairymen, however, can feed somewhat heavier than they do without much fear of overfeeding. A case is recorded in Nebraska of a dairyman who was displeased with a certain cow and decided to fit her for the butcher. In order to do so he began to feed to fatten her and was surprised to have her jump

very quickly into the class of profit makers. The dairyman, however, who plans on heavier feeding should also improve his stock.

Some dairymen could improve their feeding by greater regularity both in time of feeding and in quantity of feed. Cows in full flow are quite sensitive also to the quality of feed. Cheap feed often becomes very expensive in the end because of poor results secured from its use. The poorer feed can be utilized to better advantage by the growing stock, the bulls, or the dry cows.

Better Management of Pastures. In dairy sections pastures often remain for a number of years. In such cases it is important that the pasture be established with care to secure a good stand of desirable varieties of pasture plants. Many pastures are being maintained that scarcely produce half as much as they should because there was not sufficient pains taken to establish them properly. Often times they are not permitted to become well enough established before turning the stock on them. Pasture should be permitted to make a fairly heavy growth before the stock is turned on for the first time. A common mistake is to have all pasture within one inclosure, turn on the stock very early in the spring and keep the pasture cropped so close throughout the entire season that the production is reduced to a minimum. The amount of animal food that can be produced on a pasture during a season depends very largely upon the leafy growth that is available to digest the raw material drawn from the soil. If a field is pastured so close that there is practically no leaf growth above the ground, very little elaboration of plant food can take place. It is better to give the cows some supplementary feed rather than to permit them to crop the pasture too close. It is a good plan to divide the pasture into two or three parts and turn the stock on to the pastures in rotation without permitting too close cropping at any time. A prominent Washington dairyman has estimated that the production of his pasture was trebled by dividing and pasturing the divisions in rotation.

More Attention to Crop Production. Many dairymen feel that since their primary interest is in the dairy they are not particularly concerned about the production of crops and, therefore, make little effort to till the soil properly and utilize their manure efficiently to produce heavy crops. The result is that they harvest a light crop

of hay, a light crop of roots or of grain to be fed to cows, without realizing that the feed comes to the cows at twice the cost that it might if more attention had been given to the production of the crops. Such dairymen watch the price of feed closely and try to buy as cheaply as possible but do not realize that the skill with which they produce their crops is really determining the cost of their home-grown feed, and that they have the determining of its cost much more nearly in their own hands than in the case of purchased feeds.

Better Utilization of Manure. In some sections of the United States, the manure is considered the chief source of profit from the dairy, but in the newer sections of our country the majority of dairymen do not take the manure question seriously. The average value of manure per 1000 pound cow per annum, if all were saved and utilized with such efficiency as to recover the commercial value of its fertilizing ingredients, is calculated by Prof. F. J. Sievers, Head of the Department of Soils of the State College of Washington, to be \$41.86 on the basis of pre-war prices for commercial fertilizers. Practically half this value is in the liquid manure. While it is doubtless impossible in practice to recover full value, in many cases the profits from the herd might easily be increased \$10 to \$15 per head by saving the manure carefully at the barn, preventing the loss of the liquid portion and getting the whole product onto the fields with a minimum loss. The net return from manure is often times increased by introducing some crop into the rotation that responds more profitably to the stimulus of fertilizer than the average forage crop. In some cases the location of the dairy justifies the insertion of a vegetable crop or of certain fruits, the production of which is sometimes increased \$10 to \$15 or more per acre per ton of manure applied.

Several dairymen have been found in western Washington who have produced \$500 to \$1000 worth of vegetables or small fruits per acre on heavily manured tracts in localities where the normal production would not reach half those sums. Such large returns are not possible for the majority but the examples illustrate an important principle in farm management that should not be overlooked.

More Economical Utilization of Labor. Table VII shows that man labor constituted 25.3 per cent or practically one-fourth the net

cost of producing milk, when all counties and both years were averaged, and that it is decidedly the biggest single item of expense of operating a dairy next to the feed bill. That there is a possibility of reducing the labor cost very materially in many cases is seen by comparing individual farms on which the labor cost varied from 1.25 hours of labor per 100 pounds of milk to 4.89 hours per 100 pounds of milk. It is interesting to note, however, that the wide difference between these two extremes was not due so much to difference in the management of the labor as in the producing capacity of the herds to which the labor was applied. The herd that produced at an average labor cost of 1.25 hours per 100 pounds of milk averaged 17,473 pounds per cow, the highest production of all the herds studied; while the herd producing milk at a labor cost of 4.89 hours per 100 pounds of milk averaged 3502 pounds of milk per cow, the second lowest producing herd of all studied. The lowest producing herd averaged 3362 pounds of milk produced at a labor cost of 4.88 hours per 100 pounds or only .01 hours better than the second lowest producing herd. These figures illustrate the fact that one of the best ways to reduce the labor cost per unit, or relative labor cost, is to apply the labor to cows that will respond and further emphasize the fact brought out in preceding paragraphs that one of the best ways to increase profits is to increase the producing capacity of the cows. The highest producing herd mentioned above produced an average net profit of \$88.15 per cow, while the lowest producing herd averaged a net loss of \$56.79 per cow.

The possibilities of improving the labor management are better shown by the variation in the amount of labor expended per cow, by different dairymen which ranges from 103 hours per cow to 349 hours per cow per year. These variations are comparatively independent of production, since the majority of operations require about the same length of time whether the cow is a high or low producer. There are several good features of labor management followed successfully by various dairymen that are overlooked by others. Good managers work out a regular routine for each helper which they follow every day, so that each becomes familiar with his own routine and not only can do each job more quickly but can pass from one job to the next with the least loss of time. The writer observed one rather extreme case where no one person was assigned to any particular portion of

the work but each looked to the boss for assignment from job to job. The efficiency of the mens' time was reduced twenty-five per cent.

Some hurry back and forth from feed bin to the individual cows, feeding one or two at each trip, while others do the same work in half the time by moving the feed for the whole herd in a box or vat mounted on wheels along the alley in front of the cows, feeding as they go. The same applies to silage. Some dairymen require two or three times as much time as others for feeding hay because of awkward arrangement of mows and chutes. One dairyman was visited who had reduced the total cost of feeding hay and caring for his manure by a very simple plan. The first floor of the main part of his barn was an undivided space in which the cows, were permitted to run loose. Hayracks extended along each side wall. The second story was entirely for hay storage. An opening was left in the floor of the mow along the full length of each side just over the feed racks. In filling the barn the hay was not extended over the openings, so that the hay could be rolled directly into each feed rack with a minimum of carrying in the mow and with no work at all on the first floor. The cows were placed in stanchions in a wing for grain feeding and to be milked and were turned loose in the main barn the balance of the time. By keeping the main part bedded it was sufficient to clean out the manure whenever the dairyman's time and the field conditions made it possible to haul it direct to the field, thus saving the extra handling at the barn that usually goes with the daily cleaning of stanchions. Furthermore, almost 100 per cent of the fertilizing elements of the manure was saved.

Some dairymen equip with mechanical devices that save much time. One dairyman was observed fastening or unfastening twenty-five cows in a string with one stroke of a lever which moved a long rod passing across each stanchion, thus effecting a material saving on a single operation.

Some plan all alleys, gates and paddocks so that a minimum of attention to the animals is required after they are unfastened. Others waste considerable time moving animals to and from paddocks and pastures, often through several gates past other stock or past tempting crops.

In short, the most economical utilization of labor requires a careful study of the arrangement of stalls, alleys, feed bins, hay

chutes, paddocks, etc., and of the organization of the daily chores of each man. The percentage of the total expense that was put into labor varied in 1920 on different farms from 16.7 per cent to 39.8 per cent or a difference of 23.1 per cent. If the man who spent 39.8 per cent of his entire cost of producing milk on labor could have operated on as low a labor cost as the other man, he could have saved 23.1 per cent of his gross cost of producing milk, a handsome profit in itself. This, of course, is an extreme case, but there is room for many dairymen to make a saving of from five to ten per cent gross cost of producing by better labor management.

A More Economical Unit. Frequently too few cows are kept to be managed economically. Where one man gives his entire time to the dairy it is important to have enough cows to make full use of his time, for a smaller number breaks up a man's time so completely that it is very difficult to do any other work. Some dairymen are found devoting one man's time to a dozen cows while others handle 20 to 25 cows with one man's time.

There are very few jobs about a dairy in which the time required increases in proportion to the number of cows. On many jobs two dozen cows would scarcely require over fifty per cent more time than one dozen cows. Some jobs require almost the same time regardless of the number of cows, such as driving to and from pasture. Where the dairy man markets his own product, the cost of marketing per unit of product is reduced nearly in inverse proportion to the size of the herd (except in case of retailing). Supplies generally may be purchased and delivered more economically for a large than for a small unit.

A good sized herd may be housed equally well at a less cost per cow than a small herd. Where each dairyman keeps his own sire the use of a first class bull becomes almost prohibitive with a small herd. Sire service on the farms studied ran as high as \$23.82 per cow for one dairy with ten cows.

Economical Building Equipment. The building costs in this study for 1920 ranged from \$2.96 to \$23.35 per cow. While many of the cheaper buildings are inadequate, it is seldom that the more expensive buildings increase either the quantity or the quality of milk in proportion to the extra expense. It must be borne in mind

that so far as milk production is concerned, the function of a cattle barn is to protect the cows from the weather, provide a comfortable place for them to eat and lie down, provide arrangements for caring for them economically, and provide the sanitary conditions essential to the health of the cows and to the production of milk of good quality. Any expense incurred for cattle barns beyond providing for these essentials is a loss so far as the cost of production is concerned. Undue building expense is due in some cases to too elaborate buildings, while in other cases it is due to poorly planned structures that provide for too few cows for the size and cost of the buildings. Many, perhaps the majority, of dairymen are obliged to utilize what they find on the place, but where new structures or alterations of old structures may be contemplated plans should be carefully worked out so that a given expenditure may care for a maximum number of cows so far as it is consistent with economy of operation and the general appearance of the farmstead.

The foregoing are some of the outstanding ways by which the cost of producing milk may be reduced. No attempt has been made to enumerate all the possible ways by which cost may be reduced. While some dairymen manage poorly in only one or two particulars, others need to make a little improvement in nearly all phases of their business.

Summary of the Facts Brought Out in this Study

The following summary is based on a study of 91 farms in 1919 maintaining 1502 cows which produced 10,148,381 pounds of milk, and 81 dairy farms in 1920 maintaining 1,469 cows that produced 10,341,074 pounds of milk.

The average size of herds for two years was: Whatcom County, 18; Snohomish County, 20; Pacific County, 13; and Wahkiakum County, 20.

The average production of milk per cow per year for 1919 was Whatcom, 7,942 pounds; Snohomish, 6,864 pounds; Pacific, 5,563 pounds; and Wahkiakum, 6,328 pounds.

The average production of butterfat per cow per year for 1919 and 1920 was: Whatcom, 345 pounds; Snohomish, 297 pounds; Pacific, 251 pounds; and Wahkiakum, 319 pounds.

The average quantities of ingredients fed per cow per year with all counties averaged was as follows: grain, 1218 pounds; hay, 2,635 pounds; succulents, 3,246 pounds; pasture, 214 days, and man labor, 158 hours.

The average net cost of production per cow per year for 1919 and 1920 was: Whatcom, \$223.47; Snohomish, \$203.19; Pacific, \$156.77; and Wahkiakum, \$170.27; weighted average of all counties \$196.73.

The average cost of producing 100 pounds of milk for 1919 and 1920 was: Whatcom, \$2.81; Snohomish, \$2.96; Pacific, \$2.81; and Wahkiakum \$2.68; weighted average of all counties \$2.84.

The average cost of producing one pound of butterfat in 1919 and 1920 was: Whatcom, 64.7 cents; Snohomish, 71.5 cents; Pacific, 62.3 cents; and Wahkiakum, 63.4 cents.

Feed constituted 51.99 per cent of the net cost of producing milk in Whatcom; 49.14 per cent in Snohomish; 46.76 per cent in Pacific, 47.61 per cent in Wahkiakum; and 50.22 per cent with all counties averaged.

Man labor constituted 23.52 per cent of the net cost in Whatcom, 24.51 per cent in Snohomish, 20.14 per cent in Pacific, 27.39 per cent in Wahkiakum and 25.30 per cent as the weighted average of all counties.

The "Credits Other Than Milk" averaged 4.97 per cent of the "gross cost" of producing for all counties studied.

The basic requirements of feed and labor for producing 100 pounds of milk are as follows: grain 17.7 pounds, hay 38.2 pounds, succulents 47.1 pounds, pasture 3.1 days, man labor 2.3 hours. The total value of these basic requirements equals 75.52 per cent of the net cost of producing milk. To determine the average cost of producing milk at any time, divide the market value of the basic requirements by .7552.

The average cost of producing milk varied from \$1.94 to \$4.39 per 100 pounds in 1919, and from \$1.81 to \$4.56 per 100 pounds in 1920.

In 1919 a price of \$3.40 per 100 pounds would have covered the cost of producing 85 per cent of the total milk produced by the herds studied.

In 1920 a price of \$3.40 per 100 pounds would have covered the cost of producing 90 per cent of the total milk produced by the herds studied.

The studies indicate that the chief ways to reduce the cost of production are by the use of better stock, by better feeding and by better labor management.

Material reductions in cost also may be made in many cases by operating larger units, by better management of pastures and more attention to crop production, better planned buildings and better utilization of manure.

5
J. B. Bradford.

STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

DIVISION OF ENTOMOLOGY AND ZOOLOGY

Tolerance of San Jose Scale to Sprays

By
A. L. MELANDER

BULLETIN No. 174
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*In co-operation with the United States Department of Agriculture.

**In co-operation with Chelan County and dairy farm Organizations.

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TOLERANCE OF SAN JOSE SCALE TO SPRAYS

By

A. L. Melander, Entomologist

INTRODUCTION

Historical.—The San Jose scale has been present in Washington for approximately forty years. Introduced in the Walla Walla region and the older orchards on the Snake River it has spread in the meantime to most of the orchards of the valleys of the Columbia River and its tributaries, following that region known biologically as the Upper Sonoran life zone. It rarely, if ever, occurs at an elevation above 2000 feet, and in Western Washington is barely able to maintain itself, occurring on only a few trees in the inland southern part of the state.

Fruit growers, years ago, found the application of a lime-sulphur spray the most satisfactory control measure. Formerly this spray was commonly used at the rate of 1 lb. of sulphur to 2 lbs. lime to $\frac{3}{4}$ lb. salt to 3 gallons water. Investigations by C. V. Piper and R. W. Thatcher in 1902, reported in Washington Bulletin No. 56, showed that salt was unnecessary and that four times as much lime was being used as was chemically needed. This investigation indicated also that weaker sprays were equally efficient, a formula of 1 lb. sulphur, $\frac{1}{2}$ lb. lime to 5 or 6 gallons water giving results almost identical with those from the customary spray. In even as brief a period as a week after the application examination showed almost complete destruction of the scale. The experiments upon which these findings were based were carried on in a Snake River orchard that had been rendered commercially unproductive because of heavy infestation of San Jose scale.

During the next ten years fruit growers here and there expressed dissatisfaction with the results from lime-sulphur. At first

the omission of salt was held responsible, then the lack of excess lime, then the general usage of factory manufactured clear cold concentrate which was displacing the hot home-made lime-sulphur, and lastly that the San Jose scale was becoming tolerant to annual baths of lime-sulphur until a progressive immunity was developed.

The Spraying Project.—Beginning in 1908 the writer undertook a series of experiments to determine whether the San Jose scale varied in its susceptibility to lime-sulphur and whether races were being selectively bred that manifested an increasing tolerance to this insecticide. This has been continued each year to date and has brought out many interesting data which are here abridged and summarized, the discussion being presented in the chronological order in which the experiments were conducted. Naturally the plan of the experiment changed during its course. The early field examinations with hand lenses to determine the relative effectiveness of the several treatments gave way to a careful accounting for every insect, examined in the laboratory under the binocular microscope. Treatments found useless were discarded. Concentrations of sprays were altered, and from time to time insecticides of local interest were given comparative trials.

All the spraying was done with Bordeaux nozzles at about 175 pounds pressure. The branches selected for counting were drenched, probably more than in commercial spraying, to insure actual wetting of every individual scale. The problem was not to measure thoroughness of application but to test the relative effects of various insecticides. Obviously branches picked at random in an orchard commercially sprayed would lack that assurance of careful covering which was necessary for this undertaking. About three weeks after the application sample branches were obtained from each experiment and the scales were examined by crushing with dissecting spears under the binocular microscope. The condition of each whether living or dead was recorded by tally counters operated by the feet. Only the immature black overwintering scales were examined and recorded, as in Eastern Washington the mature scales are all winter-killed. Flat; non-mealy, dried scales were not considered, as such had died long before the experimental applications. In nearly every instance the samples were divided into two parts and examined by the

entomologist and the assistant entomologist, thus obtaining a check on each other. Since personality in interpretation did not appear to be as disturbing as the differences in individual branches the numbers of scales examined have been here added together, irrespective of who made the counts, in order to secure as many representative cuttings as possible and to insure brevity in presentation.

Acknowledgments.—In conducting this investigation many people have been called upon for assistance. The State Fruit Inspection Service has time and again rendered the greatest aid in locating suitable orchards. To Messrs. Chas. Andrus, Forbes E. Bailey, C. P. Clausen, W. L. Close, P. S. Darlington, M. L. Dean, F. E. DeSellem, George Ferguson, I. R. Fletcher, Charles Galbraith, Frank George, Chas. W. Hauck, Geo. Isaman, E. B. Kelley, Harry L. Miller, T. O. Morrison, Luke Powell, Chas. L. Robinson, R. C. Stockdale, S. W. Usher, C. L. Whitney, J. B. Wiley, C. B. Wood, E. G. Wood and others of the State Horticultural Division we express our appreciation of their courtesies despite numerous intrusions upon their time. Manufacturers and dealers in spray materials have given friendly aid in these experiments. To the owners of the various orchards who have often suffered financial loss from the application of a weak or an untried insecticide, our gratitude is due. The authorities of the Experiment Station, Directors R. W. Thatcher, Ira D. Cardiff and E. C. Johnson, have been particularly sympathetic and have made it possible to defray from the Adams research funds the major expenses of the investigation. The Assistant Entomologists of the Experiment Station, at first M. A. Yothers and later Anthony Spuler, have helped in making all applications and have shared in the tedious labor of classifying the many thousands of scales recorded in the following pages.

Polysulphid Sprays.—When sulphur and lime are boiled in a small quantity of water a chemical reaction sets in resulting in the formation of new materials, the polysulphids of calcium, which give a reddish-yellow color to the liquid. The polysulphids, represented by the chemical formulae CaS_2 , CaS_3 , and CaS_4 , are not stable substances. They are eager for oxygen, with which they unite, to become converted first into calcium thiosulphate, or CaS_2O_3 , and ultimately into calcium sulphate, or CaSO_4 . It is this affinity for oxygen which

is supposed to give lime-sulphur at least part of its insecticidal value, for if the oxygen is furnished by the insect which has been sprayed death results from chemical suffocation. Similar reactions take place when sulphur is boiled with potash, lye, or baryta, forming the polysulphids of potassium, sodium or barium.

Progressive Immunity.—Curves plotted from the early information regarding the action of lime-sulphur sprays on San Jose scale indicated that year by year this insect was becoming increasingly tolerant to this universally used insecticide, particularly in the Snake River Valley. Whether this indication was due to faulty information, to insufficient data, or to an actual progressive acclimatization it is now impossible to determine. As will be shown by the subsequent pages the scale in the lower Clarkston flats has throughout the investigation manifested an astounding resistance to polysulphid sprays, but this resistance had reached its apparent maximum by the time the investigation was begun.

Judging from the changing nature of many other species there is no inherent reason why the San Jose scale should not become altered in its ability to withstand the action of an insecticide. Algae living in hot springs, the petroleum fly that develops in crude petroleum, insects breeding in the hypertonic water of alkali lakes or of brine vats are outstanding examples of the possibility of survival in a changed environment that would have originally been fatal. Experimentally it has been possible to produce altered races of bacteria and protozoa by subjecting them generation after generation to solutions of increasing toxicity. Quayle has recorded the existence of local races of orange scale insects tolerant to the usual fumigation with cyanide-gas.

When scales are sprayed with lime-sulphur they are virtually all subjected to a new environment. If the bath were absolutely lethal all scales should succumb. But it is a matter of repeated experience that scales do not all die at the same rate and that here and there some particularly vigorous individuals remain alive and growing until after the lime-sulphur has dissipated its insecticidal properties. Thus among individuals inherently varying in tolerance there are a few per 1000 or per 10,000 that are completely resistant and these are selected through the action of the spray to be the sole progenitors

of subsequent generations. If each generation were sprayed such survivors could plausibly produce a race upon which lime-sulphur would ultimately have little or no effect. But where four summer generations or so are permitted to breed with no inhibiting sulphur effects other than might come from the thin crust of residue the advantage gained would become lost by regression. There is also the possible explanation to consider that tolerance to lime-sulphur need not be hereditary. The individuals that become acclimatized to a lime-sulphur coating may be somatically modified without genotypic selection. Each wintering generation would then reacquire its tolerance.

Restricted Distribution.—That the San Jose scale manifests different behavior in different districts is apparent. The continued devastation year after year at Clarkston, despite heavy spraying, is in sharp contrast to the easy control of the species about Wenatchee. We have observed the present innocuousness of the San Jose scale in its original home in the Santa Clara Valley of California, where the race is apparently dying out. Outside of the austral life zones the species has rarely obtained a foothold. In the State of Washington the transition life zone is virtually free of San Jose scale. We have repeatedly endeavored to raise the species at Pullman, invariably without success. Literal millions of scales have been brought to Pullman only to perish. We have tied scores of scaly apples on trees; we have time and again intertwined scaly branches on young apple trees; we have tried to graft scaly scions; we have painstakingly transferred thousands of new-born young on to potted trees in the insectary; and yet every attempt has failed to acclimatize the scale to Pullman conditions. A few of the transferred scales in the insectary have lived to complete part of their development, but have covered themselves with a loose, fuzzy, whitish exudation wholly unlike the normal flat scale. Why some scales can withstand the drastic action of a spray treatment yet all succumb to the subtle influences of the transition life zone is still a mystery. The bearing of the restricted distribution on the application of horticultural quarantine laws is obvious.

Characteristics of the Habitat of the San Jose Scale.—Within the austral life zone in Washington, following the valleys of the Columbia River and its tributaries, conditions are remarkably

homogeneous. Although Clarkston is some two hundred and fifty miles distant by river from Wenatchee or Yakima, this distance does not connote a similar great divergence in altitude, climate, soil, rainfall, aridity of atmosphere, severity of winter, summer temperature, length of growing season, amount of wind, etc. To one unfamiliar with the physiography of Washington the differences in response to spraying manifested by the San Jose scale might be ascribed to environmental differences due to the great distances between the localities. However, distance has had its main effect in the isolation of biological strains, rather than in the development of varied living conditions. The following table, presenting some of the data that concern the environment at the several stations where the experiments were conducted, shows the similarity in weather conditions despite the spread of the localities.

Table 1. Climatological Data on Spraying Localities

A. Physiographic Statistics

Locality	Altitude	Longitude	Latitude	Annual Precipitation	Annual Mean Temp
Clarkston- Lewiston	757	117 02'	46 25'	13.50	53.2
Walla Walla	975	118 20	46 04	17.16	53.4
Yakima	1067	120 31	46 36	8.96	50.8
Wenatchee	743	120 19	47 25	13.57	49.4
Kennewick	370	119 07	46 12	6.46	53.9
Prosser	661	119 46	46 13	8.37	51.8
Sunnyside	747	120 00	46 20	6.79	50.8
Cashmere	797	120 28	47 31		
Moxee	1000	120 31	46 37	8.9	
Pullman	2536	117 10	46 44	21.39	47.4

B. Minimum Temperatures

	Jan.	Feb.	Dec.	Last Frost Spring	First Frost Fall
1912 Wenatchee		18	11		
Lewiston-Clarkston		25	21		
Yakima-Moxee		16	13		
Walla Walla		27	23		
1913 Wenatchee	-3	-3	21		
Lewiston	2	-1	15		
Yakima-Moxee	-1	-7	15		
Walla Walla	12	5	17		
1914 Wenatchee	7	-1	3	Apr. 27	Nov. 6
Lewiston	29	5	8	Mar. 28	Nov. 7
Yakima-Moxee	8	13	-9	Apr. 29	Oct. 22
Walla Walla	26	10	8	Feb. 18	Nov. 15
1915 Wenatchee	1	14	-1	Mar. 26	Oct. 24
Lewiston	17	25	11	Mar. 26	Nov. 7
Yakima-Moxee	-13	14	1	May 15	Sep. 28
Walla Walla	12	27	12	Mar. 26	Nov. 7
1916 Wenatchee	-15	3	-7	Apr. 23	Oct. 2
Lewiston	-13	4	4	Mar. 24	Oct. 5
Yakima-Moxee	-14	9	-11	May 11	Sep. 28
Walla Walla	-7	9	5	Mar. 14	Oct. 8
1917 Wenatchee	-1	6	4	Apr. 22	Oct. 17
Lewiston	8	20	27	Mar. 30	Oct. 18
Yakima	0	10	15	May 5	Oct. 17
Walla Walla	9	14	20	Mar. 30	Oct. 18
1918 Wenatchee-Trinidad	9	7	11	Apr. 4	Oct. 25
Lewiston	6	16	6	Apr. 8	Nov. 12
Yakima	7	10	7	May 19	Oct. 29
Walla Walla	10	16	13	Apr. 8	Nov. 8
1919 Wenatchee-Trinidad	7	17	-19	May 5	Sep. 27
Lewiston	5	16	-23	Apr. 12	Oct. 10
Yakima	4	16	-24	Apr. 12	Sep. 29
Walla Walla	9	24	-14	Apr. 15	Oct. 24
1920 Wenatchee-Trinidad	11	23	20	Apr. 4	Oct. 31
Lewiston	12	23	26	Apr. 8	Oct. 23
Yakima	10	20	12	Apr. 9	Oct. 15
Walla Walla	12	24	15	Apr. 3	Oct. 31
1921 Wenatchee-Trinidad	11	17	11	Mar. 14	Oct. 23
Lewiston	18	14	16	Apr. 8	Oct. 23
Yakima	10	15	6	Apr. 26	Sep. 12
Walla Walla	12	19	11	Apr. 4	Oct. 23

Relation of Winter Weather to Vitality of Scale.—The relation of severity of winter weather to the vitality of scale during the subsequent spring is shown by comparing the temperature record with the mortality data. The temperature at Wenatchee usually ranges a few degrees colder than at Clarkston and since Wenatchee scales are less sturdy the inference might be drawn that the difference is due to colder weather. Again, the scale at Clarkston was most easily destroyed during the spring of the years 1914, 1916 and 1920, when the minimum temperatures attained 5, -13 and -23 degrees respectively. At Clarkston the scale manifested most resistance during 1915, 1917 and 1919, when minimum temperatures registered 8, 4 and 5 degrees respectively. Such evidence would indicate a definite correlation between winter weather and subsequent vitality of the San Jose scale. While in general this is undoubtedly true, the evidence over a period of years at Wenatchee shows in part negative correlation, and therefore lessens the absolute value of this conclusion. At Wenatchee best results were had during the years 1915, 1919 and 1921, when minimum temperatures reached 1, 7 and 11 degrees. The scales showed greater resistance to sprays in 1913, 1917 and 1918, when minimum temperatures preceding the spraying were -3, -7 and 4 degrees, respectively.

The Spraying Experiments

Experiments of 1908 and 1910.—The experiments of Piper suggested that the degree of concentration of lime-sulphur was not all important, inasmuch as a spray used at half the customary strength gave efficient returns. Shortly afterward the Division of Chemistry of the Washington Experiment Station collected numerous samples of lime-sulphur as prepared and successfully used by various fruit growers of the Wenatchee district. Strange to say, owing to the difficulties of home preparation, not one of these samples analyzed to the expected strength. The fact that sprays weaker than 4 degrees Beaume were being extensively employed led the present entomologist in 1908 to try out in a preliminary way at Clarkston various concentrations of lime-sulphur with a view of determining the most economical effective strength to recommend for San Jose scale. The results observed two weeks later are summarized in the following table.

Table 2. Experimental Spraying at Clarkston, 1908

Material	Formula*	Average % Alive
Factory-made lime-sulphur	1:8	5
Factory-made lime-sulphur	1:11	1.2
Factory-made lime-sulphur	1:14	1.4
Factory-made lime-sulphur	1:17	3
Home-made lime-sulphur	1:2:4	80
Home-made lime-sulphur	1:1:4	0
Home-made lime-sulphur	1:1:5	0
Home-made lime-sulphur	1:1:6	Many alive

*In the following tables dilutions of factory-made lime-sulphur are given in parts of concentrate to parts of water; home-made lime-sulphur in pounds of sulphur, pounds of lime, to gallons of water; dry sulphid preparations in pounds of material to gallons of water.

The erratic nature of lime-sulphur was shown by this experiment. For instance, in the first test a dilution of 1:8 gave complete kill on three trees and but 80 per cent. kill on the fourth. Two trees sprayed with one-half this strength (1:17) showed much better returns than the fourth tree mentioned.

In 1910 similar experiments were conducted at Walla Walla. Again individual trees were drenched with the spray to be tested and in about two weeks representative areas of the bark were examined under the hand lens and by crushing the immature insects the percentage of mortality was determined. The results of these tests are summarized in Table 3.

Table 3. Experimental Sprayings at Walla Walla, 1910

Material	Dilution	Average % Alive
Factory-made lime-sulphur	1:17	6
Factory-made lime-sulphur	1:9	10
Factory-made lime-sulphur	1:11.5	26
Factory-made lime-sulphur	1:14	24
Factory-made lime-sulphur	1:16	10
Orwood	1:8	65
Orwood	1:10	18
Orwood	1:12	62
Orwood	1:14	28
Check	unsprayed	60

Orwood was a wood distillation product consisting mainly of crude pyroligneous acid. Applied at full strength to a branch of a blossoming peach tree it killed the branch but not the Lecanium scale insects on the branch. Full strength lime-sulphur similarly applied did not injure either the branch or the Lecaniums. Orwood used 1:5 on peach branches, however, did no harm. It was this experiment that an overzealous reporter heralded in the morning newspaper as having killed or injured every tree treated with Orwood, and the afternoon newspaper, elaborating on the morning account, announced that the entire orchard was destroyed. Truly the peach branch had multiplied during the day. Libel suit by the manufacturers of this innocuous material was averted only by the editorial retraction that an investigation disclosed that there was no foundation for these statements and that it was strange that a state official should thus pervert the facts!

Experiments in 1912.—Beginning with 1912 the experiment was expanded and results were thereafter computed on the basis of microscopic dissections. The introduction of several specific remedies for San Jose scale enabled a comparison between treatments with standard lime-sulphur and with the newer sprays. Through cooperation with several of the district fruit inspectors sprayed branches were secured and where full data were forthcoming the results from checking such branches are worthy of record. In order to condense the statistical information as fully as possible only the most pertinent data are enumerated in the following tables.

Table 4. Results of Spraying for San Jose Scale, 1912**A. Experimental Spraying at Clarkston (Examination 17 days after application)**

Material used	No. Scales Examined	% Alive
Check	1472	97.0
Lime-sulphur 26 deg.	882	74.4
Lime-sulphur 5.3 deg.	371	85.7
Lime-sulphur 4.5 deg.	789	73.3
Lime-sulphur 3 deg.	2430	93.7
Lime-sulphur 2 deg.	983	78.8
Lime-sulphur 1½:½:5 (3 deg.)	833	96.0
Lime-sulphur 1:2:5 (3 deg.)	983	97.8
Lime-sulphur & Fe SO ₄	1440	93.7
Lime-sulphur & NaCl	449	46.7
Lime-sulphur & CaO	1096	63.3
Crest, 4%	731	79.5
Crest, 2%	568	63.0
Scalecide, 10%	544	16.4
Scalecide, 5%	1214	58.4

B. Growers' Applications

Locality	Material Used	Days Interval	No. Scales Examined	% Alive
Yakima	Lime-sulphur, 3 deg.	17	1270	14.8
Sunnyside	Crest, 2%	12	480	83.3
Prosser	L-S., 2:1:9=3½ deg.	20	2443	0.4
Prosser	Crude oil emuls., 12%	18	614	0.0
Kennewick	Rex L-S., 1:11	4	913	1.4
Wenatchee	Rex L-S., 1:9	9	990	0.9
Wenatchee	Rex L-S., 1:10	6	377	6.6
Wenatchee	Rex L-S., 1:10	12	1891	0.6
Walla Walla	Rex L-S., 1:8	20	218	25.0
Wawawai	L-S., 15:15:50, hot	28	957	0.7
Clarkston	Lime-sulphur 6 deg.	76	415	21.7
Clarkston	L-S., 3:4:10, 3 applications		807	52.8

In explanation of the formulae in Table 3, the lime-sulphur was furnished by the Rex Spray Company; 1:2:5 indicates 1 lb. sulphur and 2 lbs. lime boiled and diluted to make 5 gallons; Crest spray was

manufactured in Seattle, its principal ingredient being fir oil; the last citation for Clarkston represented three successive hot applications during March, the second one week after the first and the third two weeks later, the scales being counted April 12.

A perusal of the data of Table 4 shows that in 1912 the San Jose scale at Clarkston behaved in a different way from the scale elsewhere in Washington. It was so remarkably resistant to lime-sulphur of whatever strength that even seventeen days after the spraying the insects showed but little effect from their polysulphid bath. At Walla Walla the scale showed partial tolerance but in the other districts of Washington the San Jose scale was held in practical control by treatments of lime-sulphur. It must be mentioned that Table 4 includes only those counts where the time between spraying and counting was known. Forty additional samples were examined from other localities, submitted by the fruit inspectors a reasonable time after the applications had been given, but as the exact date of spraying was not known the data are not here presented. These samples, however, confirmed the previous conclusion. In every instance Clarkston scales showed remarkable resistance as compared with those from other localities.

Experiments in 1913.—The fact that lime-sulphur is generally a valuable treatment for San Jose scale, and that while formerly it was effective at Clarkston it does not now afford complete control, caused the entomologists to conduct the investigation with a view to the possibility of a progressive immunity being established in the lower Clarkston district. In order to have definite means of comparison identical solutions were applied by the Experiment Station entomologists in March, 1913, at Clarkston, Walla Walla, Kennewick, Sunnyside, Yakima and Wenatchee. Samples from the sprayed trees were examined three times at approximately biweekly intervals. Discussions of some of the results of the 1913 experiments have been given in the *Journal of Economic Entomology*, Vol. VII., pp. 167-172 (Apr. 1914) and in the Tenth Report Washington State Horticultural Association, pp. 134-141 (1914). The data from the counts are presented in Table 5. It will be noticed in this table and elsewhere that sometimes a thousand and more scales are insufficient to establish a rate of mortality in conformity with expectancy. Such discrepan-

cies, due to local differences in vigor of scale or host, emphasize the need of many counts, repeated year after year, in order to determine the absolute value of treatments.

Table 5. Experimental Sprayings, 1913

A. Clarkston. (3977 Checks, average 71% alive.)

Material	15 Days Scales	% Alive	30 Days Scales	% Alive	45 Days Scales	% Alive
Lime-sulphur, 5 deg.	5789	91	3248	68	5470	10
Lime-sulphur, 3 deg.	5999	94	4408	72	2816	13
Lime-sulphur, 2 deg.	1898	28	2440	76	3332	23
Lime-sulphur, 1:2:5	1270	72	2127	60	4494	16
Lime-sulphur, 1:½:5	4668	68	4178	74	5378	21
Soda-sulphur, 3 deg.	1277	94	....	..	1928	6
Orchard misc. oil 5%	9095	4	8420	0.5	9993	0.0
Spramulsion, 1:15	5948	63	4335	42	6293	12
Fuel oil emuls., 10%	4991	22	3214	0.4	5122	0.0
Crest, 1:40	4882	21	597	27	1153	52

B. Walla Walla. (823 Checks, 44% alive.)

Lime-sulphur, 5 deg.	1053	76	2150	14	1200	0
Lime-sulphur, 3 deg.	1009	58	1860	23	2000	0
Lime-sulphur, 2 deg.	469	54	786	17	1500	0
Lime-sulphur, 1:2:5	740	36	1274	9	1000	0
Lime-sulphur, 1:½:5	397	39	1027	14	....	..
Orchard oil, 5%	533	35	1757	3	....	..
Fuel oil emuls.	1559	9	1550	0	....	..
Rex L-S., 3 deg.	1176	52	688	9	....	..
Crude oil emuls.	1192	7	803	0	6685	0

C. Kennewick, (352 Checks, 88% alive.)

Lime-sulphur, 5 deg.	2180	41	3695	0.5	....	..
Lime-sulphur, 3 deg.	1581	37	3480	0.3	....	..
Orchard oil, 6%	1566	40	2765	0.0	....	..

D. Prosser.

Lime-sulphur, 3 deg.	894	89	1425	5	....	..
Lime-sulphur, 2 deg.	1230	83	1096	30	....	..
Lime-sulphur, 1:2:5 deg.	2677	89	1338	1	....	..
Lime-sulphur, 1:½:5 deg.	758	76	1277	1	....	..
Soda-sulphur, 3 deg.	2146	95	1418	1	....	..
Fuel oil emuls.	3802	71	2500	0	....	..

E. Sunnyside. (1832 Checks, 93% alive.)

Lime-sulphur, 5 deg.	726	60	1322	6	665	0.0
Lime-sulphur, 3 deg.	566	78	1023	3	930	0.5
Lime-sulphur, 2 deg.	1130	76	1251	4	2280	0.0
Lime-sulphur, 1:2:5	1303	58	1616	4	4090	0.0
Lime-sulphur, 1:½:5	4643	93	4061	2	14,745	0.3
Orchard oil, 5%	2161	13	3400	0	10,620	0.0
Crude oil emulsion	1456	91	1900	0	7865	0.4
Spramulsion, 6%	1469	50	2376	7	3534	2.4

F. Yakima. (1020 Checks, 93% alive.)

Material	15 Days Scales	% Alive	30 Days Scales	% Alive	45 Days Scales	% Alive
Lime-sulphur, 5 deg.	4652	55	3454	38	14,021	0.2
Lime-sulphur, 3 deg.	2970	79	2639	43	....	..
Lime-sulphur, 2 deg.	1737	76	2114	39	2621	0.6
Lime-sulphur, 1:2:5	1546	50	1278	22	937	0.2
Lime-sulphur, 1:½:5	3503	87	3958	32	9310	0.1
Orchard oil, 5%	2120	6	3000	0	3150	0.0
Spramulsion, 6%	1921	44	1521	2	2410	2.5
Crude oil emulsion	570	60	2800	0	3760	0.0

G. Wenatchee. (1048 Checks, 78% alive.)

Lime-sulphur, 5 deg.	2463	34	1063	30	....	..
Lime-sulphur, 3 deg.	2108	55	1268	59	....	..
Lime-sulphur, 2 deg.	2203	50	970	14	....	..
Lime-sulphur, 1:2:5	2275	0.7	690	6	....	..
Lime-sulphur, 1:½:5	3864	24	1727	34	....	..
Orchard oil, 5%	3532	0	2960	0	....	..
Spramulsion, 6%	3123	6	2185	11	....	..
Fuel oil emuls.	3730	1	2060	0	....	..

Experiments in 1914.—During the spring of 1914 the Entomologist was absent on leave and the spraying experiments were conducted and recorded by M. A. Yothers. Table 6 summarizes the results obtained.

Table 6. Spraying Experiments, 1914

A. Clarkston. (755 Checks, 91% alive.)

Material	Interval 15 Days		28 Days	
	No. Scales	% Alive	No. Scales	% Alive
Lime-sulphur, 5 deg.	2697	6.3	2787	1.1
Lime-sulphur, 3 deg.	2498	7.0	1745	3.0
Lime-sulphur, 2 deg.	....	..	3287	2.3
Lime-sulphur, 2 deg. and lime	3007	6.4	3527	1.5
Soda-sulphur, 3 deg.	1517	85.7	2022	11.4
Orchard misc. oil, 1:15	6950	0.0	5000	0.0
Spramulsion, 1:15	2086	75.0	1171	30.0
Spramulsion, 1:10	4373	3.0	2552	1.4
Fuel oil emuls., 1:10	6710	0.0	6620	0.0
Redwood's spray, 1:10	2518	9.4	2520	4.0
Crest, 1:40	3016	91.2	1658	83.5

B. Walla Walla.

Lime-sulphur, 5 deg.	2663	7.5	2377	1.1
Lime-sulphur, 3 deg.	4379	16.2	6090	1.5
Lime-sulphur, 2 deg.	1878	42.7	1638	10.2
Lime-sulphur, 1:½:5 (2.5 deg)	2494	11.8	1926	1.3
Soda-sulphur, 3 deg.	2359	89.5	1709	13.7
Orchard misc. oil, 1:15	6795	0.0	5000	0.0
Orchard misc. oil, 1:20	8970	0.06	5000	0.0
Spramulsion, 1:15	2680	86.5	891	20.0
Crude oil emuls., 1:10	6077	0.6	1740	1.4
Redwood's spray, 1:10	2937	12.3	3266	13
Crest, 1:40	2622	91.0	1510	86.5

C. Sunnyside.

Material	Interval 13 Days		Interval 27 Days	
	No. Scales	% Alive	No. Scales	% Alive
Lime-sulphur, 5 deg.	4137	6.5	4299	0.5
Lime-sulphur, 3 deg.	3069	11.8	3820	1.3
Lime-sulphur, 3 deg. & lime	3147	2.4	3862	0.4
Lime-sulphur, 1:½:5	1569	12.0	4059	1.1
Soda-sulphur, 3 deg.	2918	87.1	3607	2.7
Orchard misc. oil, 1:15	10,785	0.0	7740	0.0
Orchard misc. oil, 1:20	6745	0.0	6195	0.0
Spramulsion, 1:10	3427	12.1	4683	1.1
Fuel oil emuls., 1:10	8535	0.0	6640	0.04
Crude oil emuls., 1:10	9490	0.0	6445	0.0
Redwood's spray, 1:10	2320	16.2	4827	0.4
Crest,	3188	91.0	2060	86.4

D. Yakima.

Material	Interval 13 Days		Interval 27 Days	
	No. Scales	% Alive	No. Scales	% Alive
Lime-sulphur, 5 deg.	3431	3.8	2920	0.5
Lime-sulphur, 3 deg.	1081	25.8	3743	0.5
Lime-sulphur, 1:½:5	1693	22.5	2745	1.1
Soda-sulphur, 3 deg.	2054	84.5	3048	2.1
Orchard misc. oil, 1:15	4675	0.0	1907	0.3
Orchard misc. oil, 1:20	4445	0.2	1070	0.4
Crude oil emuls., 1:10	3841	0.5	2600	0.4
Redwood's spray, 1:10	1505	28.3	2078	1.1

E. Commercial Spraying at Clarkston.

Material	Interval	No. Examined	% Alive
Lime-sulphur, 3 deg.	9 days	1432	2.2
Fuel oil emuls. (Laundry soap)	9 days	5005	0.0
Fuel oil emuls. (Whale-oil soap)	9 days	4150	0.0
Fuel oil emuls.	14 days	6295	0.1
Fuel oil emuls.	14 days	4275	0.0
Fuel oil emuls.	14 days	4470	0.0
L.-S., 1:7, 2 applications	16 days	2544	4.1
L.-S., 1:7	16 days	2512	5.1
Lime-sulphur, 5 deg.	29 days	2160	10.5
Lime-sulphur, 1:5	26 days	1836	11.8
L.-S., 3 deg. (Kept in insectary)	31 days	328	16.7

Notes.—Fuel oil or crude oil emulsion was based on 1 qt. oil, 5 ozs. fish oil soap and 0.8 oz. lye, boiled with sufficient water and then diluted. The Orchard Brand miscible oil was obtained from the Thomson Chemical Company, Baltimore. Spramulston was prepared by the Roger's Chemical Company, San Francisco. Redwood's spray was a sulphid-containing emulsion locally manufactured in the Yakima Valley. Crest Spray, a wood distillation product, was prepared by the Crest Chemical Company, Seattle, and was used at prescribed strength.

Observations.—Fuel oil, the residue after the volatile gasoline and kerosene have been removed from crude oil, is difficult to emulsify. Hence where growers have tried to utilize fuel oil their spraying has usually been spotted. Some parts of the bark have been drenched with oil with entirely effective results against the scale insects, but with doubtful safety to the trees, while adjacent portions have been wet with water and a little emulsifier. In such areas the scales show little or no effect from the spraying. Such irregularity in spread from a poorly made emulsion has caused many a grower to abandon the usage of home-made oil sprays.

On September 11 an inspection was made of the trees sprayed in the Clarkston experiments. All the trees showed much scale on twigs, leaves and fruit. Apparently the oil-treated trees were more nearly freed of scale in the spring, but summer invasions negated the results, the scale insects being better able to thrive on the oil-cleaned bark than on trees still showing the residue of lime-sulphur. Throughout the lower Clarkston district the San Jose Scale was abundant, rendering nearly all fruit unmarketable.

Experiments of 1915.—In the spring of 1915 more attention than previously was given to this project. Additional materials and concentrations were tested and results were tallied at three biweekly periods with a further count later at Clarkston and Yakima. As heretofore Clarkston scales showed a most remarkable resistance to polysulphid sprays, while Wenatchee scales showed great susceptibility to spraying. In fact at Wenatchee great difficulty was experienced in finding sufficient scale insects for experiments. The data of Table 7 summarize the results.

Table 7. Spraying Experiments, 1915

A. Clarkston (1239 Checks, 88.4% alive.)

Material	20 days		35 days		50 days		70 days	
	Total Scales	% Alive	Total Scales	% Alive	Total Scales	% Alive	Total Scales	% Alive
L-S., 10 deg.	1088	58.6	1214	41.6	510	27.5	637	43.3
L-S., 5 deg.	651	35.4	969	42.2	493	39.3	656	45.2
L-S., 3 deg.	494	92.1	1058	58.7	1363	47.2	681	45.5
L-S., 2 deg.	531	69.2	790	63.3	719	61.4	604	32.5
L-S., 1:½:5	408	92.9	983	50.3	477	60.5	701	49.2
L-S., 1:2:5	825	72.2	590	37.5	771	61.6	679	60.2
S-S., 3 deg.	622	85.6	846	52.1	927	67.8	625	44.3
S-S., 2 deg.	582	97.0	937	68.4	804	66.8	649	46.8
S-S., 1½ deg.	651	84.5	1682	58.8	500	62.4	705	59.4
Synthetic S. S.	386	96.2	982	76.5	510	70.6	400	69.2
Colloid S.	925	31.2	1065	66.8	671	84.0	578	58.9
NaOH, 3 deg.	252	75.8	660	63.8	501	82.2	419	88.7
Hypo, 3 deg.	622	85.6	....	....	....	....	....	....
Orchard em., 5%	1493	8.3	813	5.5	513	2.9	622	3.2
D. S. O., 10%	739	29.6	422	0.0	870	0.2	685	0.0
D. S. O., 5%	....	37.5	671	11.5	541	4.6	....	....
Misc. No. 1, 10%	425	2.6	543	0.0	549	0.0	436	0.0
Misc., No. 1 5%	1330	46.6	1220	6.5	927	1.6	618	0.6
Buggo, 5%	305	84.0	477	88.4	494	88.1	427	53.7
Crude oil, 10%	709	32.7	399	0.8	923	17.1	1008	6.8
Crude oil, 8%	395	6.3	836	3.6	695	9.5	505	5.3
Crude oil, 5%	666	49.8	403	9.4	466	65.7	679	3.5
Fuel oil, 10%	980	10.7	267	1.5	521	1.7	769	2.6
Fuel oil, 5%	725	3.7	817	5.3	532	27.9	454	3.5
Crest, 10%	945	24.0	441	96.7	833	81.3	723	80.8
Crest, 5%	783	84.3	840	88.2	898	89.4	671	77.4
Dake powder	323	97.3	505	87.3	1142	93.2	425	84.5
Check	1239	88.4	238	98.4	537	94.2	512	54.8

B. Yakima (Sprayed March 7.)

	21 days		38 days		51 days		83 days	
	Total Scales	% Alive	Total Scales	% Alive	Total Scales	% Alive	Total Scales	% Alive
L-S., 5 deg.	524	33.2	243	21.0	1049	4.1	505	10.1
L-S., 3 deg.	870	45.2	1551	21.8	1068	1.1	517	3.3
L-S., 2 deg.	454	34.1	228	36.8	869	3.0	700	7.7
L-S., 1:½:5	....	....	1073	10.5	912	4.6	527	8.3
S-S., 3 deg.	898	34.5	1147	41.8	840	9.6	699	24.9
Na ₂ S ₂ O ₃ , 3 deg.	610	82.0	508	65.3	455	49.0	479	47.2
NaHSO ₃ , 3 deg.	481	47.4	591	40.6	866	58.4	489	35.4
NaOH, 3 deg.	642	86.5	520	44.6	303	59.7	530	57.0
Redwood's, 1:10	1000	28.6	679	12.2	855	4.9	602	7.3
Redwood's, 1:20	649	58.6	629	34.0	895	7.9	789	23.4
Orchard oil, 5%	1043	1.4	710	0.6	1059	0.3	600	0.0
Crude oil, 10%	1257	26.2	846	20.1	887	16.6	783	31.7
Crude oil, 5%	785	50.5	794	26.1	1116	27.2	703	31.2
Dormant sol. oil, 6%	....	....	1066	0.0	....	....	....	....
Check	795	86.4	684	83.5	714	66.5	751	73.9

C. Yakima (Sprayed March 26)

	21 days		38 days		62 days	
	Total Scales	% Alive	Total Scales	% Alive	Total Scales	% Alive
Lime-sulphur, 3 deg.	1339	27.5	336	24.1	273	26.4
Lime-sulphur, 2 deg.	290	22.4	105	47.6	146	49.3
Lime-sulphur, 1 deg.	548	20.4	823	47.4	337	34.5
S-S., 3 deg.	246	41.8	436	31.0	467	48.3
S-S., 2 deg.	616	49.0	447	48.4	226	43.3
S-S., 1 deg.	259	75.0	420	61.2	339	37.7
NaSx, 3 deg.	654	84.4	766	28.1	649	46.5
NaSx, 1 deg.	749	39.4	583	28.6	1217	26.2

D. Walla Walla (Sprayed March 5)

	20 days		38 days		55 days	
	Total Scales	% Alive	Total Scales	% Alive	Total Scales	% Alive
L-S., 5 deg.	932	49.5	1162	35.7	703	37.3
L-S., 3 deg.	631	53.9	1212	31.9	798	23.3
L-S., 2 deg.	668	57.8	1250	32.3	1364	26.1
L-S., 1: ½ :5	222	58.1	1004	36.8	743	50.3
S-S., 3 deg.	689	31.8	1959	25.5	732	33.4
S-S 2 deg.	722	26.1	936	42.7	856	45.2
Orchard oil, 5%	772	0.9	1380	0.0	1168	0.0
Crude oil, 10%	1010	10.0	1086	2.5	943	2.8
Crude oil, 5%	682	25.0	1000	10.2	851	58.7
Check	885	90.8	643	93.5	845	75.8

E. Wenatchee (Sprayed March 11)

	20 days		37 days		61 days	
	Total Scales	% Alive	Total Scales	% Alive	Total Scales	% Alive
L-S., 5 deg.	550	44.5	697	2.3	367	1.4
L-S., 3 deg.	1034	24.5	615	0.8	379	1.6
L-S., 2 deg.	532	48.8	639	3.0	317	2.2
L-S., 1: ½ :5	518	37.3	648	2.5	272	1.8
S-S., 2 deg.	433	39.2	723	1.1	114	1.8
Orchard oil, 5%	583	0.0	700	0.0	293	0.0
Crude oil, 10%	520	2.5	540	0.0	423	0.0
Crude oil, 5%	321	0.3	686	21.6	...	...
Check	481	35.8	353	66.9	239	45.2

F. Sunnyside (Sprayed March 5)

	22 days		39 days	
	Total Scales	% Alive	Total Scales	% Alive
L-S., 5 deg.	642	10.3	325	12.0
L-S., 3 deg.	430	4.4	340	15.9
L-S., 2 deg.	556	22.6	173	26.0
L-S., 1: ½ :5	639	8.6	145	2.1
S-S., 3 deg.	625	4.8	859	18.2
S-S., 2 deg.	418	7.4	284	24.3
Orchard oil 5%	874	0.3	1020	0.0
Crude oil, 10%	1109	2.5	898	6.0
Crude oil, 5%	660	0.0	1176	7.0
Check (Poplar)	679	83.2	706	92.7
Apple	731 at date of spraying = 27.6 alive			

G. Commercial Spraying at Walla Walla; interval 10 days.

Material	Total	% Alive
Buggo, 14%	390	0.5
D. S. O., 7%	643	0.0
L-S., 3 ½ deg.	516	62.0
L-S., 5 deg.	476	52.3

Notes.—Soda-sulphur, abbreviated S-S. in the tables, was used at the rate of 1 ½ lbs. to 5 gallons, testing 3 degrees B., and 1 lb. to 5 gallons, testing 2 degrees. The soda-sulphur used was the Niagara Soluble Sulphur Compound. Inasmuch as this insecticide was being given wide publicity, an extensive factory being established at Seattle for its general use at ultra-weak dilutions, more attention than previously was given to this material in the experiments. A synthetic soda-sulphur was tried, made at the suggestion of George Olson, Washington Station Chemist, according to the following formula:

Freshly ppt. sulphur liquid 2 qts.
Hypo ($\text{Na}_2\text{S}_2\text{O}_3$) 2 ozs.
Lye (NaOH or KOH) 1 oz.
Sodium sulphite (Na_2SO_3) ½ oz.
Water 1 qt.

These ingredients were also tried separately. Precipitated colloidal sulphur was prepared by adding a little more than 4 ozs. hydrochloric acid to the quart of concentrated lime-sulphur, previously diluted 1 to 13. It will be noted that neither the synthetic compound, nor its ingredients, showed any practical insecticidal value and at Clarkston the factory-made product likewise gave a negative reaction.

Buggo, a California oil product, could not be well emulsified. Similar experience was reported by various fruit growers, although good results were said to be obtained in California with this brand. Dake tree powder was administered in a ¾-inch auger hole in the trunk. It proved to be worthless. Crest, used at 5 per cent and 10 per cent strength, altho its accompanying directions prescribed 1:50 for winter spray, gave no appreciable benefit. Particularly at Sunnyside, where the water is heavily charged with alkali, it was found difficult to emulsify crude oil. Results from spraying with crude oil emulsion were generally erratic. Spots where many live

scales were found adjoined areas where the kill was perfect. It appeared as if with the heterogeneous emulsion the oil of the more concentrated portions failed to spread to the scales wet with the more watery portion on subsequent drying.

An abridgment of the records of 1915 was published in the *Journal of Economic Entomology*, Volume 8, pp. 475-480, Oct. 1915. Discrepancies in percentages between those given in previous publications and here are due to differences in the method of interpreting data. In the articles the percentages obtained independently by Mr. Yothers and the writer were averaged without regard to the number of scales examined. In the present discussion the living and dead scales were totaled, irrespective of who made the examination, and then the final percentages were computed.

Experiments in 1916.—Experiments on the vitality of the San Jose scale were continued in 1916 at Clarkston, Walla Walla and Yakima. The materials used and the comparative effects of the treatments are set forth in Table 8.

Table 8. Spraying for San Jose Scale, 1916

A. Clarkston (Sprayed March 27; Checks 92.4 % alive)

Material	Interval 28 days		48 days	
	Total Scales	% Alive	Total Scales	% Alive
Lime-sulphur, 10 deg.	1256	0.2	1153	0.5
Lime-sulphur, 5 deg.	1485	2.1	1861	1.2
Lime-sulphur, 3 deg.	3171	3.8	1719	3.1
Lime-sulphur, 2 deg.	1284	2.9	750	1.2
S-S., 5 deg.	207	12.1	653	4.3
S-S., 3 deg.	1077	6.9	1347	6.2
S-S., 2 deg.	1303	20.4	1404	7.6
S-S. liquid, 5 deg.	754	5.8	681	0.0
S-S. liquid, 3 deg.	1103	6.0	882	3.5
S-S. liquid, 2 deg.	1103	6.0	1204	3.5
B. T. S., 3 deg.	799	13.3	939	17.8
Orchard oil, 5%	1214	0.0	1240	0.1
D. S. O., 6%	606	37.3	984	7.7
D. S. O., 4%	572	41.3	696	48.6
D. S. O., 3%	810	56.2	780	44.1
Misc. oil, 5%	807	25.9	421	20.9
Ker. emuls., 10%	1208	3.8	934	1.8
Ker. emuls., 5%	947	17.7	148	23.0
Crude, 5% & K., 5%	600	0.0		
S. S., 1½ deg. & oil, 3%	1313	10.0	982	3.4
Check	912	79.5	778	76.0

B. Walla Walla (Sprayed March 30; Checks 26.2 %)

	Interval 30 days		56 days	
	Total Scales	% Alive	Total Scales	% Alive
Lime-sulphur, 5 deg.	984	0.8	958	4.1
Lime-sulphur, 3 deg.	929	4.1	778	6.0
Lime-sulphur, 2 deg.	1019	4.4	572	4.4
S-S., 5 deg.	940	8.0	533	2.6
S-S., 3 deg.	1264	9.2	912	5.5
S-S., 2 deg.	649	9.5	519	5.4
D. S. O., 6 deg.	1246	0.2	262	0.0
D. S. O., 5 deg.	1178	0.9	361	0.6
D. S. O., 4 deg.	1015	9.8	459	0.4
Misc. oil, 5%	977	0.7	1055	0.0
L-S., 2 deg. & Nic.	2746	9.4	1307	6.5
S-S., 1 deg. & Oil 3%	1101	1.2	825	0.0
Check	1246	39.4	678	55.8

C. Yakima (Sprayed April 1; Checks 65.3%)

	Interval 30 days		52 days	
	Total Scales	% Alive	Total Scales	% Alive
Lime-sulphur, 10 deg.	763	0.0	732	0.0
Lime-sulphur, 5 deg.	999	0.3	1014	0.4
Lime-sulphur, 3 deg.	1107	1.2	793	3.0
Lime-sulphur, 2 deg.	950	0.2	792	1.1
Sludge, 10 deg.	972	0.2	971	0.6
Sludge, 5 deg.	709	0.9	953	2.0
Sludge, 2 deg.	899	1.2	534	1.1
S-S., 3 deg.	938	2.0	716	0.1
S-S., 2 deg.	756	2.1	1037	0.4
S-S. liquid, 2 deg.	787	2.7	918	1.8
S-L., & Nicotine	1026	2.8	775	3.2
S-S. & oil	720	1.1	900	2.3
B. T. S., 3 deg.	894	8.4	1277	6.3
D. S. O., 6 deg.	1134	0.0	1309	0.2
D. S. O., 5 deg.	888	0.9	292	0.3
D. S. O., 4 deg.	1030	0.8	769	0.5
Check	416	55.1	783	58.3

D. Commercial Spraying, Clarkston

Material	Sprayed	Interval	Total	% Alive
L-S., 7 deg.; K. em., 1%	Mar. 9 & 27	54 days	1055	15.3
L-S., 6 deg.	Mar. 2 & 16	60 days	867	2.9
D. S. O., 6%	Mar. 16	47 days	1098	17.1
K. em., 1½%	Mar. 8	53 days	835	19.3
K. em., 1%	3 applications	May 2	960	2.7

Notes.—In making lime-sulphur more or less insoluble sludge always accumulates. This material consists of impurities and oxidized lime-sulphur and holds a considerable amount of liquid in absorption. Some growers have been utilizing such sludge in spraying and it was to determine what insecticidal value it possessed that the tests were made. The sludge was mixed with water to dilute to proper hydrometer test. The ten degree sludge practically white-washed the trees.

The addition of nicotine to the dormant spray of lime-sulphur is a common recommendation. This combination was tested to determine if nicotine increased the insecticidal value of a dilute lime-sulphur when used on San Jose scale. A 0.1 per cent solution of

nicotine sulphate (Blackleaf 40) was added to a 2 degree lime-sulphur, but no betterment was observed.

Soda-sulphur liquid was prepared by boiling together one part of sulphur with 0.75 part lye, the heat of slaking the lye causing spontaneous chemical combination.

Barium-sulphur, abbreviated in the tables B. T. S., from the trade name barium tetrasulphid, did not prove to be a dependable treatment for San Jose scale.

During the spring of 1916 a propaganda advocating the use of a 1 per cent kerosene emulsion in dormant treatment for scale was heralded through the Clarkston district. In the tests a 5 per cent emulsion of kerosene proved utterly ineffective.

The most widely used miscible oil in 1916 was Dormant Soluble Oil (abbreviated D. S. O.) manufactured by the General Chemical Company of San Francisco. The formula used at that time did not produce nearly as reliable an oil as the Orchard Brand made from Pennsylvania crude oil.

Owing to the difficulty of emulsifying heavy crude oil, a mixture thinned with equal parts of kerosene was tried at 10 per cent strength at Clarkston, with perfect success.

The material tabulated as Miscible Oil 5 per cent was an experimental oil furnished by the California Spray Chemical Company.

Observations.—By the time of the second count the males were emerging at Clarkston.

Red spider eggs hatched on trees treated with lime-sulphur, but the young mites soon died. Eggs were killed when sprayed with oil or soda-sulphur liquid.

Winter-kill was greater than usual. At Wenatchee on April 4 an examination of 1051 scales showed only 18 per cent alive, the survival varying on different branches between 0.6 per cent and 46 per cent. Hence no spraying was attempted at Wenatchee.

An examination during September of the experimental trees at Clarkston showed severe infestation of fruit, foliage and branches on all trees. Those relatively freest of scale had been treated with kerosene emulsion 7 per cent, lime-sulphur 5 degrees and 3 degrees, and soda-sulphur liquid 2 degrees. Owing to free movements of young scales in spreading from tree to tree observations made at the

end of the summer are not regarded of much value in determining relative value of spray treatments in experimental plots.

Experiments of 1917.—Spraying experiments were continued during the spring of 1917 at Clarkston, Yakima and Wenatchee. Dry lime-sulphur, Scalecide and a spray oil manufactured at Hood River were added to the materials tested. The results of the several treatments are given in Table 9.

Table 9. Experimental Spraying, 1917

A. Clarkston, (Sprayed March 31; Checks 89.4% alive)

Material	17 days		42 days		69 days	
	Total	%Alive	Total	%Alive	Total	%Alive
Lime-sulphur, 12 deg.	969	20.0	856	34.7	760	11.6
Lime-sulphur, 5 deg.	973	43.3	988	10.0	1028	14.1
Lime-sulphur, 4 deg.	1316	83.1	677	13.9	1057	11.7
Lime-sulphur, 3 deg.	1430	87.6	366	18.0	1233	13.8
Lime-sulphur, 5 deg.	1223	90.5	645	19.9	970	9.1
Dry L-S., 1:4	1758	89.0	1008	17.0	1073	22.3
Dry L-S., 1:5	1428	91.3	1078	15.1	1012	20.2
Dry L-S., 1:6	1666	89.5	948	17.3	1023	23.4
S-S., 1:4	1081	71.7	1168	22.2	1123	13.8
S-S., 1:5	1456	82.8	1128	22.5	1166	33.3
S-S., 1:6	1590	88.4	975	22.2	1193	20.9
Orchard oil, 5%	1671	1.6	1274	0.9	1255	0.3
D. S. O., 6%	1325	2.8	1235	0.0	1546	0.8
D. S. O., 5%	1701	4.2	1150	0.0	1420	2.5
Scalecide, 6%	1780	2.9	1070	0.0	1028	0.4
Scalecide, 5%	1518	2.8	1611	0.2	1065	0.0
Hood River oil, 6%	1599	1.9	1031	0.3	1008	1.1
Hood River oil, 5%	1661	3.1	1295	0.5	1515	0.5
Check	788	90.0	1038	52.6	816	55.3

B. Yakima (Sprayed April 8)

	25 days		51 days	
	Total	%Alive	Total	%Alive
Lime-sulphur, 10 deg.	1273	3.1	1314	0.0
Lime-sulphur, 5 deg.	879	8.0	1117	0.8
Lime-sulphur, 3 deg.	1279	7.9	1173	1.5
Lime-sulphur, 2 deg.	906	5.1	1349	3.8
S-S., 1:4	1521	11.4	1021	2.1
S-S., 1:6	678	22.7	1199	2.9
D. S. O., 6%	828	0.0	1138	0.0
D. S. O., 5%	1671	0.0	985	0.0
Check	960	67.8	1223	50.3

C. Wenatchee (Sprayed April 10; 1201 Checks, 49.7%)

	24 days		51 days	
Lime-sulphur, 5 deg.	661	9.4	365	0.5
Lime-sulphur, 3 deg.	2037	13.8	1253	1.0
Lime-sulphur, 2 deg.	1136	16.7	1601	0.7
S-S., 1:5	636	30.0	293	2.0
D. S. O., 6%	666	0.0	504	0.4
D. S. O., 5%	1107	0.0	702	0.0
Check	465	68.7	180	1.1

Owing to the dearth of living scales in sufficient abundance for experiment at Wenatchee part of the spraying was repeated at Cashmere, nine miles up the Wenatchee River. The table combines the results at both places.

Experiments in 1918.—During the late fall of 1917 a heavily infested apple tree was transplanted from Clarkston to Wenatchee and another from Wenatchee to Clarkston. This exchange of trees was made to determine whether winter climate or inherent differences affected the susceptibility of scale to lime-sulphur wash.

Ultra-strong polysulphid sprays were tried at Clarkston to see if the San Jose scale there could be exterminated by any practical lime-sulphur spraying. Owing to a general impression that late sprayings are most effective some tests were put on at Clarkston on April 22 when early varieties of apples had the center flowers fully open, late varieties were beginning to leaf out and the San Jose males were in the black-eyed prepupa condition. The effect of the late spraying on the scale insects is tabulated below. On the trees the soda-sulphur caused much leaf scorching, the oil slight scorching and the lime-sulphur no visible harm. New growth replaced leaf injury and there was no diminution in the setting of fruit so that no permanent harm was done. The experiments for the year are summed up in Table 10.

Table 10. Spraying Experiments, 1918

A. Clarkston. (Spraying March 12; 439 checks, 78.5%)

Material	21 days		42 days		72 days	
	Total	%Alive	Total	%Alive	Total	%Alive
Lime-sulphur, 12 deg.	584	11.8	962	14.9	678	16.4
Lime-sulphur, 8 deg.	622	12.8	570	7.2	494	22.1
Lime-sulphur, 5 deg.	607	20.8	734	18.7	449	13.8
Lime-sulphur, 4 deg.	542	25.0	887	26.4	966	22.0
Lime-sulphur, 3 deg.	551	22.3	670	23.0	600	26.0
Lime-sulphur, 2 deg.	613	19.6	771	24.8	899	16.5
Dry L-S., 1:2	547	9.2	716	10.0	679	29.2
Dry L-S., 1:3	509	14.7	827	23.0	553	19.9
Dry L-S., 1:4	334	31.2	527	24.3	551	21.5
Dry L-S., 1:5	223	18.8	572	29.6	697	28.0
S-S., 1:2	541	10.9	708	17.8	916	20.9
S-S., 1:4	533	27.2	702	23.0	729	22.9
S-S., 1:5	509	10.9	1049	22.9	626	25.2
D. S. O., 6%	547	0.0	1090	0.0	2351	0.0
D. S. O., 5%	574	0.2	356	0.6	265	0.0
D. S. O., (1916) 5%	473	0.2	407	0.0	....	...
Scalecide, 6%	511	0.0	685	0.0	....	...
Scalecide, 5%	553	0.0	650	0.0	5002	0.0
Wen'chee tree L-S., 3 deg.	131	10.0	648	5.7	237	11.4
Check	604	88.8	592	73.3	593	54.8

B. Clarkston (Sprayed April 22)

	30 days		51 days	
	Total	% Alive	Total	% Alive
L-S., 4 deg.	665	23.0	302	25.5
L-S., 3 deg.	932	26.9	409	22.2
S-S., 1:4	593	13.0	232	17.2
S-S., 1:5	813	40.3	332	34.1
D. S. O., 5%	924	1.5	...	...

C. Walla Walla (Sprayed March 15; 412 checks, 78.2 %)

	22 days		46 days	
	Total	%Alive	Total	%Alive
Lime-sulphur, 10 deg.	635	0.6	1292	0.7
Lime-sulphur, 5 deg.	791	1.1	1350	1.1
Lime-sulphur, 4 deg.	1968	7.2	2842	1.1
Lime-sulphur, 3 deg.	2468	11.9	3572	1.3
Lime-sulphur, 2 deg.	774	5.7	1892	0.9
Dry L-S., 1:3	883	2.1	1666	1.6
Dry L-S., 1:4	2020	6.9	1989	4.2
Dry L-S., 1:5	939	9.8	1528	7.1
S-S., 1:3	837	6.8	1276	2.8
S-S., 1:4	1092	10.0	1338	10.3
S-S., 1:5	807	4.0	751	5.5
D. S. O., 6%	1343	0.4	1777	0.4
D. S. O., 5%	1350	3.1	3066	0.5
Scalecide, 6%	507	0.0	550	0.0
Scalecide, 5%	800	0.0	1800	0.0
Check	488	85.0	777	28.2

D. Yakima. (Sprayed March 16; 551 checks, 90.2 %)

	22 days		44 days	
	Total	%Alive	Total	%Alive
Lime-sulphur, 12 deg.	1155	0.4	2015	3.2
Lime-sulphur, 5 deg.	1055	0.7	1538	4.4
Lime-sulphur, 4 deg.	1282	0.5	1149	5.1
Lime-sulphur, 3 deg.	2395	0.9	2504	5.3
Lime-sulphur, 2 deg.	1576	6.2	2223	5.3
Dry L-S., 1:3	1094	2.8	1046	6.3
Dry L-S., 1:4	814	2.6	976	5.7
Dry L-S., 1:5	1127	2.3	1051	3.9
S-S., 1:3	1023	5.8	1330	4.9
S-S., 1:4	1012	16.1	1448	5.4
S-S., 1:5	1350	4.1	1336	7.2
D. S. O., 6%	2450	0.0	4566	1.2
D. S. O., 5%	1250	0.0	1510	0.0
Scalecide, 6%	1175	0.0	1470	0.0
Scalecide, 5%	920	0.0	1560	0.0

E. Wenatchee. (Sprayed March 20; 764 checks, 87.7 %)

	23 days		50 days	
	Total	%Alive	Total	%Alive
Lime-sulphur, 4 deg.	1622	12.8	918	0.1
Lime-sulphur, 3 deg.	471	4.7	460	10.9
Lime-sulphur, 2 deg.	697	14.3	1418	12.5
Dry L-S., 1:4	1001	24.0	841	3.7
S-S., 1:4	1134	22.2	1729	2.3
S-S., 1:5	876	29.1	1048	6.5
D. S. O., 5%	946	0.1	660	0.0
Scalecide, 5%	810	0.0	630	0.0
Clarkston tree, L-S., 3 deg.	935	21.8	624	14.5
Check	701	65.8	604	41.1

F. Commercial Spraying, Walla Walla

	Sprayed	Interval	To'tl.	% Alive
Lime-sulphur, 6 deg.	5 Apr.	19 days	686	1.9
L-S., 5 deg. & 6 deg.	20 Mar. & 15 Apr.	35 days	330	2.1
D. S. O., 6%	5 Apr.	19 days	2400	0.0

Notes and Observations.—The winter of 1917-18 was unusually open, which might account for the great vigor of the Clarkston scales during their growth. Winter mortality at each place visited was less than usual; at Clarkston three old last year's scales were found alive in the spring, an unduplicated observation in Washington.

Freezing weather during April selectively destroyed many male scales at Walla Walla while in the pupa state. An analysis of the males on the check tree April 30 showed dead pupae at the rate of four to each live pupa or transformed male.

Red spider eggs were all destroyed by soda-sulphur, 12 degree lime-sulphur and the oil sprays. Ten per cent of the eggs were alive at the time of the first count at Clarkston when 8 degree lime-sulphur had been used, and an increasing number lived through the weaker washes. However, the hatched young mites soon died on the trees treated with lime-sulphur. Aphid eggs were found hatched even after being sprayed with 6 per cent oil.

The ineffectiveness of polysulphid sprays in assuring complete control of scale is seen by the general distribution of the living growing insects. Even though visibly coated with encrusted spray scales here and there were completing their metamorphosis. It is not the possibility of poor application that can account for living scale.

The dropping off of the scale covering with resultant death of the unprotected insect is particularly marked with the stronger polysulphid sprays. Hence the anomaly appears in the tables of poorer results from strong sprays and of lessened effect at the last counts. By the time of the June 12th counts at Clarkston the abrasion of the insects had progressed so far as to invalidate the data with respect to the absolute value of the sprays.

Two factory brands of lime-sulphur were tried in comparison, the Rex, manufactured at Yakima, and the Petrie, made at Clarkston. The results are combined in the tables, but eight paired counts of tests of 2.3 and 4 deg. showed an average of 4.6% alive for Rex and 6.9% for Petrie, a differential of 2.3% in favor of Rex spray. The Rex is made with chemical excess of sulphur to test 33 deg. and is especially rich in the higher polysulphids. Petrie spray was cooked with chemical excess of lime and originally tested 27 degrees.

There is considerable difference in the opening of the spraying season at the places selected. Scales resumed growth at Clarkston about March 30, at Walla Walla about April 3, Yakima and Wenatchee about April 10. Red spider eggs were largely hatched at Walla Walla by April 6 but at Yakima had not begun hatching by April 9. On April 30 the male scales at Yakima had reached the pupa stage.

Table 11. Spraying Experiments, in 1919

A. Clarkston. (Sprayed March 5; 789 checks, 88% alive)

	29 days		44 days		70 days	
	Total	%Alive	Total	%Alive	Total	%Alive
Lime-sul., 12 deg.	1129	68.0	1214	29.0	1183	39.6
Lime-sul., 8 deg.	1110	64.6	937	34.6	857	43.0
Lime-sul., 5 deg.	822	71.6	1085	32.5	902	37.5
Lime-sul., 3 deg.	1905	66.0	2087	51.0	2081	43.8
Lime-sul., 2 deg.	1106	66.8	1198	53.9	1023	56.5
Dry L-S., 15:50	1108	66.8	1329	51.3	1095	43.8
Dry L-S., 10:50	954	76.7	919	55.0	512	39.5
Dry L-S., reboiled	822	58.5	888	47.4	1128	34.9
S-S., 15:50	1049	55.0	1002	35.1	1212	39.7
S-S., 10:50	829	52.6	1014	61.3	1171	48.7
D. S. O., 6%	1021	7.4	1937	1.4	1123	2.9
D. S. O., 5%	1291	9.4	1319	4.5	1186	9.0
Scalecide, 6%	1075	0.6	1525	0.3	1032	0.2
Scalecide, 5%	1070	1.6	1347	0.5	1374	0.3
Hood River, 6%	1206	0.1	1235	0.4	1421	0.0
Hood River, 5%	1558	0.1	1554	0.2	960	0.0
Check	995	83.0	1020	78.8	1057	47.0

B. Walla Walla. (Sprayed March 17 and 19; 500 checks, 84.4%)

	27 days		66 days	
	Total	% Alive	Total	% Alive
Lime-sulphur, 5 deg.	1080	8.9	1088	0.7
Lime-sulphur, 3 deg.	1114	14.1	805	8.1
Lime-sulphur, 2 deg.	1090	14.0	976	5.7
Dry L-S., 15:50	993	33.5	250	2.8
Dry L-S., 10:50	1093	28.4	770	17.5
S-S., 15:50	1249	24.7	613	7.0
S-S., 10:50	1199	28.2	421	19.0
D. S. O., 5%, A	1537	0.1	890	0.0
D. S. O., 5%, B	1322	7.6	1079	2.7
Scalecide, 5%, A	1893	0.1	985	0.5
Scalecide, 5%, B	1030	3.7	1480	0.0
Hood River 5%, A	1377	0.0	1900	0.0
Hood River 5%, B	1716	0.1	1470	0.0
Crude, 5%, A	919	18.5	1020	14.5
Carb. 5%, A	1369	69.7	165	9.1
Carb. 5%, B	1176	74.4	738	28.9
Carb. 15%, B	936	77.0	801	21.4
Crest 5%, B	1183	64.6	883	57.6
Crest 2%, B	1080	62.6	504	49.6
Check	878	74.0	240	51.3

C. Yakima. (Sprayed March 20; 500 checks, 68.6% alive)

	Alive	Total	% Alive
Lime-sulphur, 5 deg.	3	1093	0.3
Lime-sulphur, 3 deg.	128	1189	10.8
Dry L-S., 15:50	269	1082	24.9
Dry L-S., 10:50	249	840	29.6
S-S., 15:50	162	1088	14.9
S-S., 10:50	73	1031	7.1
D. S. O., 5%	0	662	0.0
Hood River, 5%	0	1129	0.0
Scalecide, 5%	0	305	0.0
Crest, 10%	152	1051	14.5
Crest, 5%	107	383	28.0
Crest, 2%	469	999	47.0
Carbolic, 5%	403	1156	35.0
Carbolic, 2%	93	321	28.9
Check	260	695	37.4

D. Wenatchee (Sprayed March 25; 320 checks, 61% alive)

	28 days		47 days	
	Total	% Alive	Total	% Alive
Lime-sulphur, 5 deg.	815	2.8	1105	3.9
Lime-sulphur, 3 deg.	1282	1.6	965	0.5
Lime-sulphur, 2 deg.	816	3.3	1068	2.2
Dry L-S., 15:50	116	14.7	313	11.2
Dry L-S., 10:50	105	15.4	165	5.5
S-S., 15:50	479	8.1	384	4.7
S-S., 10:50	301	16.3	714	10.5
D. S. O., 5%	983	5.1	424	6.4
Hood River, 5%	532	0.4	378	0.3
Scalecide, 5%	941	4.2	1070	0.7
Check	856	78.2	1030	73.2

Observations and Comments.—The interchange of small scaly trees was repeated between Clarkston and Wenatchee. The Clarkston tree transplanted to Wenatchee showed 75 per cent of 513 unsprayed scales alive on March 25th when the tree was sprayed with 3 degree lime-sulphur. Four weeks later an examination of 1228 scales showed 4.7 per cent alive. This mortality is much greater than would be expected by Clarkston scales undisturbed at Clarkston, but it should be noted that the percentage of scales alive is three times as great as with Wenatchee scales similarly treated. Much more striking, however, are the results from transplanting the Wenatchee tree to Clarkston. At spraying time an examination of 538 scales from this tree showed 75 per cent alive. Four weeks after spraying with 3 degree lime-sulphur 548 scales showed but 4.3 per cent alive whereas 66 per cent of Clarkston scales were still alive with the same treatment. At the time of the second count, 44 days following spraying all the Wenatchee scales had died, but how much of this mortality to ascribe to racial susceptibility and how much to the weakened condition of the transplanted host tree it is impossible to decide.

In the midst of the applications at Walla Walla a light drizzle set in, intermittently lasting for two days and interrupting the spraying operations. Those applications marked A were given before the rain, those B after it, but while the bark was still damp. It will be noted that better results were obtained when the trees were dry; in the case of the heavy oil emulsions perfect results being secured even though rain fell on the trees almost immediately following the applications.

Crest spray, which lately had not been exploited, was revived by a reorganized company, somewhat modified, called Standard Fir Oil Spray, and was advocated at 2 per cent strength. Even at 10 per cent strength it did not compare with weaker emulsions based on crude oil.

Standard Carbolic Emulsion, manufactured in Western Washington, was recommended by its producers at a dilution of 1:70. Even at three times this strength it failed to eradicate the scale.

Unfortunately through a mistake the experimental trees at Yakima were all resprayed by the owner with lime-sulphur six days

before the counts were made. Some allowance in interpreting results should therefore be made for this extra treatment. Scales killed by the emulsions of crude oil had died shortly after the application, but polysulphid sprays kill gradually. This error prevented the securing of later counts.

At the time of the first count, the male scales were in the black-eyed prepupal stage of development, red spider eggs had hatched, and apple blossoms were beginning to show pink. By the time of the second count adult males were emerging.

Experiments in 1920.—Spraying experiments were interrupted in the spring of 1920 because of the unusual and excessive winter mortality of the scales. In October, 1919, before the scale insects were fully ready for hibernation the temperature suddenly dropped to 12 or 14 degrees Fahrenheit. Again, in mid-December record-breaking cold weather occurred, with minimum temperatures as indicated in the following table. Hence the winter-kill of scales was unprecedented for Eastern Washington. This condition has been reported by Mr. Spuler of this Experiment Station in the *Journal of Economic Entomology*, December, 1920, pp. 443-444. Obviously with so small a scattering of living scales available on which to base records, the interpretation of comparative spraying experiments would be subject to so much error as to lose its practical value. It is for this reason that no spraying was done, and for this reason also that 1920 testimonials produced to show the efficiency of any scalecide should be severely discounted.

It is perhaps unfortunate that spraying could not have been carried on and enough extra counts made to compensate for winter-kill, in order to settle a question discussed by many fruit growers. It will be noted that winter-kill was more effective than the usual spraying in reducing the San Jose scale. Hence many fruit growers argued that spraying in the spring of 1920 would have been a needless expense because the individual scales hardy enough to withstand the winter freezes would be the same ones that would resist an insecticide. On the other hand the fruit inspectors held that it should be possible practically to annihilate the scales because the weakened condition of the survivors would render them particularly susceptible to an insecticide.

Table 12. Winter Mortality of Unsprayed San Jose Scale

Locality	Total Examined	% Alive	Minimum Temperature
Clarkston	10,144	5.4	-26
Walla Walla	12,816	3.2	-36
Yakima	8,595	1.5	-24
Wenatchee	5,409	1.8	-16
Spokane	2,485	19.2	-15
Prosser	2,545	0.0	-30
White Salmon	2,093	17.8	

The excessive cold of December, 1919, produced evidence of danger following oil spraying. As this case has been frequently quoted in the Northwest it may be referred to because of its bearing on the series of sprayings here reported. Part of the Indian Cache Ranch, located about three miles from Clarkston, was sprayed in the fall of 1919 with Scalecide. The following spring the oil-treated trees showed excessive injury, whereas the unsprayed trees escaped. From this and other similar occurrences the admonition must be made not to apply an oil spray in the fall. Even if applied in the spring an improperly emulsified spray of crude oil may cause injury, as in the case of the last drainings from the spray-tank, particularly if the tank had previously been used for lime-sulphur, but with reasonable care it should be possible to use a good mineral oil-emulsion as a dormant spray in Washington with an assurance of safety, providing the preceding winter was not excessively cold, and providing the application is made before active growth begins and after the danger of late severe freezing is past.

Apparently little is known with certainty regarding the condition under which oil might induce injury. In general it is held that an oil coating inhibits evaporation and hence when followed by a freeze the separation of excessive moisture from the cellular protoplasm becomes an irreversible reaction. Low temperature lessens sap pressure, and hence when oil is applied soon after a freeze there is greater possibility of penetration.

A tree as an organism responds to differing conditions of environment in varying degree from year to year. Oil injury is probably related to winter hardiness, and such factors as variety, maturity of tissues, soil moisture, and malnutrition due to red spider or other depredations, may be as cogent as winter temperatures in influencing injury. Oil injury is not feared in California but in Northern and Atlantic States has sometimes been a serious matter. We have sometimes noticed a retarded opening of buds on trees sprayed with strong emulsions.

Because of the difficulty of obtaining crude petroleum oil and because of the skill needed in emulsifying it we have ceased to advise the general home manufacture of crude oil sprays. Among the prepared miscible oils on the market there is much variation as this report shows. However, in those districts where a 3 degree or 4 degree lime-sulphur is not giving satisfactory results, the judicious use of a good miscible oil is to be recommended.

Experiments in 1921.—The excessive winter-kill of December, 1919, still showed its effects in the spring of 1921 in that many of the dead scales remained adherent to the branches throughout the intervening time. Often branches that at first sight seemed incrustated with scales showed only dead insects left from the fall of 1919 when subjected to close examination. There was moreover a decided dearth of live scales in many orchards. Seemingly the set-back from the severe freeze was followed by slow recovery. Under such circumstances evidence as to the absolute value of an insecticide needs to be based on more than a cursory inspection, and orchardists' testimonials adduced in 1921 should be discounted almost as severely as those from the year before.

In the following tabulations, as would also be true to a less extent in the preceding, the number of scales examined was usually far in excess of the number recorded, because those killed in the freeze of the winter before were disregarded as furnishing no information as to the value of this season's spraying. Hence data are few for certain branches received for tabulation although the sender supposed that an abundance of scale was submitted.

Table 18. Spraying Experiments, 1921

A. Clarkston. (Sprayed March 23; buds opening.)

Material	30 Days Interval	
	Total	% Alive
Lime-sulphur, 5 deg.	866	45.0
Lime-sulphur, 3 deg.	332	17.1
Lime-sulphur, 2 deg.	820	61.0
Dry L-S., 15:50	129	46.5
Dry L-S., 10:50	828	55.5
S-S., 10:50	223	34.5
B. T. S., 10:50	843	72.2
L-S., glue, oil	1075	24.5
Scalecide, 6%	1494	10.4
Dormoil, 6%	1101	0.1
Spramulsion, 6%	198	0.5
D. S. O., 6%	1115	10.8
Check	770	78.0

B. WallaWalla. (Sprayed March 22; 418 checks, 78% alive),

Material	44 Days Interval	
	Total	% Alive
L-S., 5 deg.	783	16.4
L-S., 3 deg.	863	34.5
L-S., 2 deg.	409	19.3
Dry L-S., 20:50	250	30.8
S-S., 10:50	187	40.0
Dormoil, 6%	127	26.0
Dormoil, 5%	262	5.3
Dormoil, 6% poor	606	41.8
Check	1041	67.8

C. Yakima. (Sprayed March 25)

	24 Days		36 Days	
	Total	%Alive	Total	%Alive
L-S., 5 deg.	316	1.2	530	1.9
L-S., 3 deg.	332	3.6	100	14.0
L-S., 2 deg.	610	0.0	685	6.3
Dry L-S., 15:50	494	5.9	600	27.5
Dormoil, 6%	518	0.0	350	40.1
Spramulsion, 6%	325	3.3	815	37.5
Spramulsion, 5%	300	0.0	435	0.0
Check	550	1.8	1343	53.5

D. Wenatchee (Pears, sprayed April 2; 551 checks, 70.7% alive)

	Interval 28 Days		Interval 37 Days	
	Total	%Alive	Total	%Alive
Lime-sulphur, 5 deg.	1324	4.1		
Lime-sulphur, 3 deg.	1050	2.5		
Lime-sulphur, 2 deg.	1363	10.2		
Dry L-S., 15:50	1235	27.6		
Dry L-S., 10:50	....	...	1343	8.5
S-S., 15:50	1069	19.4		
S-S., 10:50	1270	26.0		
B. T. S., 15:50	1400	15.9		
B. T. S., 10:50	1444	44.6		
L-S., glue, oil	....	...	1309	25.8
S-S., oil	....	...	1870	11.4
Spramulsion, 5%	1094	9.5	861	4.0
Dormoil, 5%	1379	1.4		

Notes.—The water used at Walla Walla for diluting the insecticides came from a shallow well and was hard. The sample of Dormoil could scarcely be emulsified with this hard water, even under careful manipulation, although identical oil emulsified well at the other localities.

The lime-sulphur, glue and oil combination was devised by Paul R. Jones as a means whereby these incompatible insecticides could be mixed. The ratio of oil, lime-sulphur and water was 1:4:40. The glue, used 1 lb. to 5 gallons of oil, was first soaked, heated till dissolved, and then worked into the miscible oil. After diluting the lime-sulphur the prepared miscible oil was added. This mixture as tested at Clarkston and Wenatchee did not show an increased efficiency.

Spramulsion, which had been off the Washington market for some years, was revived by the Sherwin Williams Company. It was too light an oil to compete with the heavier miscible oils.

At the time the counts were made males were pupating at Clarkston and Wenatchee, and emerging at Walla Walla. It seems remarkable to witness the unchecked growth of females and the pupation and emergence of males on branches heavily encrusted with polysulphid coatings.

Red spider eggs had hatched when sprayed with lime-sulphur 3 degrees, barium-sulphur 15:50, and soda-sulphur; nearly all had hatched under the glue combination; while Dormoil and Spramulsion produced nearly a perfect kill.

Experiments in 1922.—Spraying experiments in 1922 were confined to Clarkston, the applications being made on April 6. The materials used and results obtained are given in the following table.

Table 14. Spraying Experiments at Clarkston, 1922

	Interval 26 Days		Interval 52 Days	
	Total	%Alive	Total	%Alive
Lime-sulphur, 12 deg.	1277	12.8	1133	9.2
Lime-sulphur, 8 deg.	1047	10.1	328	12.2
Lime-sulphur, 5 deg.	1405	29.0	1160	20.9
Lime-sulphur, 3 deg.	409	16.4	501	21.2
L-S., 1: $\frac{1}{2}$: 5	1287	21.3	989	15.0
L-S., 1 $\frac{1}{4}$: $\frac{1}{2}$: 5	1183	27.8	567	18.0
Dry L-S., 30:50	1019	20.8	1197	17.2
Dry L-S., 15:50	....	...	1130	14.6
B. T. S., 30:50	1089	19.1	1344	23.4
B. T. S., 15:50	1523	19.5	593	14.5
L-S., 5 deg., caseinate	1157	20.0	968	17.2
L-S., 3 deg. caseinate	1142	20.5	538	13.7
L-S., 3 deg., casein, oil	772	3.4	384	1.5
Dormoil, 6%	1239	0.0	....	...
Spramulsion 10%	1181	0.0	....	...
Spramulsion 6%	1435	0.0	1121	0.6
Scalecide, 6%	1300	0.0	....	...
Ortho oil, 10%	1202	14.4	1278	21.3
Ortho oil, 6%	1130	19.5	1225	18.1
Keresol, 10%	1196	14.2	960	13.7
Keresol, 6%	1182	52.2	888	39.4
Check	394	63.7	2223	57.4

Notes on 1922 Spraying.—Among the oil sprays much difference in behavior was noticed. Scalecide and Dormoil were good, as formerly; Spramulsion was changed by its manufacturers to a much heavier miscible oil to its decided advantage; Ortho miscible oil was hard to emulsify and did not afford a uniform coating; Keresol was too light a product to use against the resistant scales of Clarkston;

one brand was not applied because of impossibility to emulsify, even under most persistent manipulation.

A prepared casein powder was used as a spreader with lime-sulphur at the rate of one pound to one hundred gallons; and also to permit a mixture containing three degree lime-sulphur and 5 per cent Scalecide. As far as the evidence goes there was a slight improvement in spread and effectiveness in the case of the lime-sulphur, but a slight impairment in the efficiency of the oil.

Even with 12 degree lime-sulphur, where the scales were incrusting with a heavy coating of the insecticide, many were growing in a way to leave no doubt of their remarkable resistance. While some that had resumed growth were dying from effects of the spray, their bodies then beginning to show a browning and their shells a stunting, the fact remains that even seven weeks after the application of a 12 degree lime-sulphur nine per cent of the scales were alive and growing, and most of these were as large, juicy and clear yellow as their unsprayed neighbors. At this writing the State's Fruit Inspector for the Clarkston district reports that his region is overrun with San Jose scale, the limbs of the orchard trees are greasy with scales, apple and pear fruit is entirely unsalable, the scales even spreading to the fruit of the cherry. As long as Clarkston fruit growers are placing their dependence on lime-sulphur, no matter how strong, the control of the scale in that region is hopeless.

SUMMARY

Tolerance to Sprays.—The adoption of lime-sulphur as a general spray for San Jose scale has been attended with varying success. Chemical and entomological studies by this Station have shown that in those districts where lime-sulphur is efficient a solution containing 1 lb. sulphur and $\frac{1}{2}$ lb. lime to about 5 gallons water is as reliable as solutions of greater density or different composition.

Whenever scale insects are sprayed with lime-sulphur they die at varying rates. Some few are killed by the first shock of chemical deoxygenation. Most linger on, some for days, some for weeks, some for months. Among individuals varying so greatly in susceptibility,

here and there are some so vigorous as to resist entirely the destructive action of this spray. A varying number of individuals escape in probably every locality, in part making necessary the annual repetition of dormant spraying; sometimes the number of survivors is a very appreciable percentage of the whole scale population.

If compulsory lime-sulphur spraying, which subjects virtually every scale to its action, thus eliminates the weaklings and selects the progenitors for future generations, a modified breed of tolerant scales could plausibly be developed. To determine if tolerance is progressively increasing the project reported was undertaken.

The Experimental Project.—Scales were given the dormant spraying to furnish the needed data for advancing conclusions. Clarkston, Walla Walla, Yakima and Wenatchee proved to be representative districts and information was based mainly on scales from these points. The following comparative aspects were considered:

- a. Lime-sulphur at various strengths in one locality.
- b. Lime-sulphur at a given strength in several localities.
- c. Lime-sulphur and various other polysulphid sprays, e. g., dry lime-sulphur, soda-sulphur, barium-sulphur, home-made sprays, thiosulphate formulae.
- d. Lime-sulphur and various oil sprays, to test strength, brands, localities.

In general, weak solutions used near the limits of effective dilution were used, with the idea of measuring relative value rather than of effecting complete control.

While the main project undertook to measure the amount and rate of mortality, incidentally information of utmost practical value was secured regarding brands, effective prescriptions, time of application, methods of spraying, effect on insects other than San Jose scale, relative costs, locality differences in emulsification of oils, amount of winter-kill, extent of danger from use of oils, etc., which has kept the Washington spraying program abreast of the times.

Methods.—Since this project was not to be a test of thoroughness of spraying but a determination of the effects of the spray, the applications were not done in a large commercial manner, but instead

a few thousand scales previously located on representative trees were carefully drenched. At intervals within two or three months after the spraying sample young scales were dissected under the binocular microscope and the rate of mortality recorded. Later counts were found to be of less value because of abrasion of dead scales. Although a thousand and more of scales were examined for each record and percentages are given to tenths of one per cent, the figures do not carry the accuracy they imply. According to the nature of the sample secured for examination the figures might vary considerably. Scales from water sprouts or from vigorous trees are sturdy. Those from scale-poisoned trees or following a severe winter are weak and die more readily. Hence is apparent the necessity of repeated checking, over a period of years, to draw satisfactory deductions as to the absolute value of an insecticide.

Interpretations.—Statistical curves have been worked out for many of the experiments. A few characteristic ones are combined and presented in the accompanying chart. A comparison of these curves shows the range of difference in their reactions to the common insecticides manifested by the local strains of the San Jose scale.

CONCLUSIONS

With Regard to Sprays Based on Sulphur.—

Sprays like lime-sulphur, soda-sulphur and barium-sulphur manifest a prolonged and progressive insecticidal action.

Lime-sulphur and soda-sulphur have greater insecticidal value than barium-sulphur.

Factory-made lime-sulphur is as satisfactory as home-made, and is more dependable in composition.

Although different formulas for lime-sulphur might show theoretical advantages or disadvantages, yet in practice any differences in results have not been consistent.

The exact concentration to use is much less important than thoroughness of application, because of:

- a. Excessive and unusual prolificness of the San Jose scale.

- b. Within reasonable limits, the similarity in results from varying concentrations.

The addition of lime, lye, nicotine, or casein spreader to lime-sulphur does not materially alter its effectiveness.

There is no experimental evidence to show that dry lime-sulphur is superior to liquid.

Individual scales resistant to a bath of lime-sulphur are almost equally tolerant to a second application.

With Regard to Oil Sprays.—

Good emulsions based on crude oil are quicker and more dependable sprays for San Jose scale than are sprays based on sulphur, such as lime-sulphur, or barium-sulphur and are less disagreeable to apply.

Lack of standardization has been a serious drawback to the universal acceptance of oil sprays. Under a given trade name miscible oils sometimes vary in composition, in physical properties and in insecticidal effect.

Poor results from oil spraying are to be expected if trees are wet at time of application, but it is not a serious matter if rain comes shortly after the application is made.

A poorly emulsified oil, or one with insufficient insecticidal value, is less effective than a low-grade lime-sulphur, probably because the oil-cleaned and softened bark affords a better breeding ground than the residual coating from a sulphid spray.

Well emulsified oils, used as a late dormant spray, following a normal winter should be depended on as safe to the trees. Fall spraying with oil is not recommended because of the possibility of heavy winter freezes and consequent injury to the trees.

Emulsions based on wood distillation products instead of crude petroleum oil have little insecticidal value.

With Regard to Control in General.—

Because the San Jose scale holds the record for rapid breeding a treatment to be considered effective must accomplish practical ex-

termination. A remedy that results in 60 per cent kill is no better than one that produces but 40 per cent, because both are useless. But a spray that kills 60 per cent of the scales should not be confused with faulty application of an efficient insecticide that reaches but 60 per cent of the scales.

The most reliable determination of the absolute or relative value of compared insecticides is not a late summer inspection of fruit, foliage or bark, but a microscopic examination of actually sprayed scales about one month after the application. Before one month the spray might not have produced its maximal effect, later the dropping of dead scales disturbs the proportion of living to dead scales, still later the free movements of young scales make deductions untrustworthy. Late summer inspections, however, are a valuable gauge of the thoroughness of application.

The best time for spraying for San Jose scale is when buds begin to swell. Later the swollen buds cover some scales out of reach of spraying. When foliage begins to appear dormant sprays may cause burning. This is especially true with soda-sulphur and crude oil emulsions.

A relative scarceness of living scales following a severe winter is not necessarily due to successful spraying. Excessive winter-kill shows its effects even into the second winter in a diminished number of live scales per tree.

The fact that a treatment has been declared effective in one locality is no assurance that it will be universally effective. Recommendations based on Atlantic Coast or Middle West conditions are not of necessity applicable to the scale district of Washington, any more than Wenatchee recommendations would suit Clarkston. Following a severe winter ultra-weak sprays show apparently good results.

The locality, winter conditions, and presence of other pests than scale should determine the kind of spray to select and the concentration best to use. The most efficient concentration is not a fixed prescription.

Where lime-sulphur is giving good results, it will possibly be given preference as a dormant spray. Where a 3 or 4 degree lime-

sulphur is giving imperfect control the use of oil sprays is recommended.

With Regard to the San Jose Scale.—

There is much variation among different individual scales in susceptibility, tolerance or resistance to sprays, particularly to sprays based on sulphur, such as lime-sulphur, soda-sulphur, or barium-sulphur.

The amount of tolerance differs from locality to locality, and from year to year.

There is more difference in the rate of kill and the total number of scales that die when comparing Clarkston and Wenatchee scales sprayed with regulation strength of lime-sulphur, than when comparing scales at either locality sprayed with lime-sulphur ranging from 2 to 27 degrees.

Winter mortality varies with severity of winter and with local vigor of scale. A temperature of -30 degrees F. destroys more scales than the usual spraying does. In a mild winter 98 per cent of the young scales may survive.

The abundance of scales at Clarkston and the relative scarceness at Wenatchee is probably largely due to a natural vigor possessed by the Clarkston scales, as manifested by a positive tolerance to lime-sulphur, and a corresponding weakness of the Wenatchee scales, as manifested by susceptibility to sprays. The difference is probably due less to external factors, like spraying methods, minimum winter temperatures, optimum summer weather, action of parasites, number of summer generations, or condition of host plants.

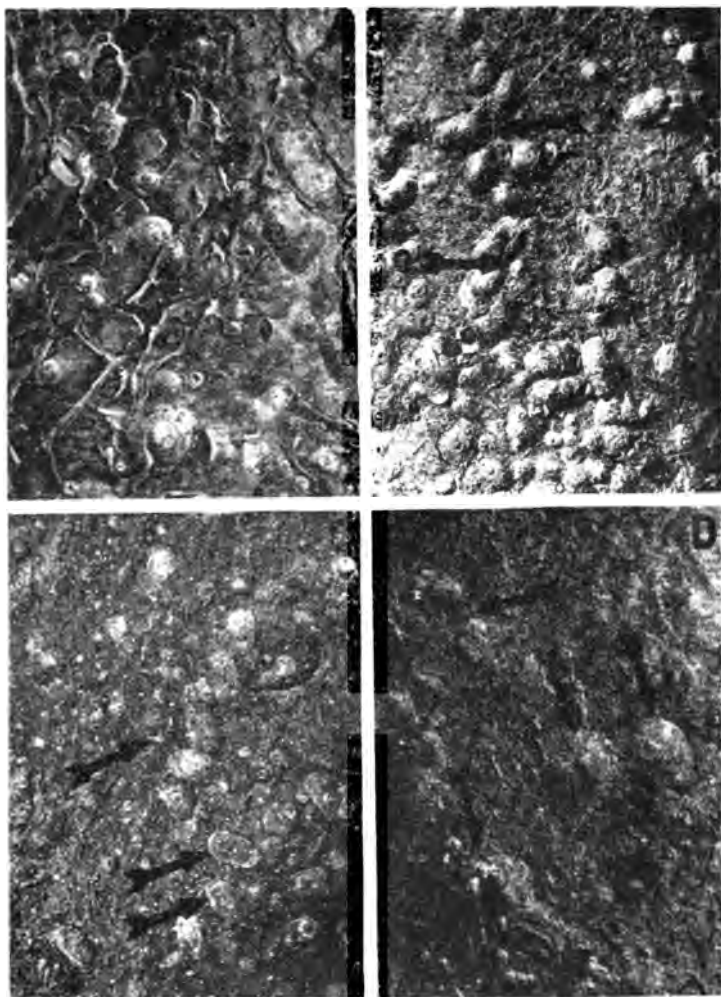
There is no positive evidence that the San Jose scale is at present becoming more and more resistant to polysulphid sprays. This is possibly the effect of hereditary regression since the annual spraying with lime-sulphur exerts selection on only one of the season's many generations. Or possibly, acclimatization to lime-sulphur is an annual acquirement, not necessarily heritable.

The distribution of the San Jose scale in Washington, and probably elsewhere, coincides with the area where peaches are success-

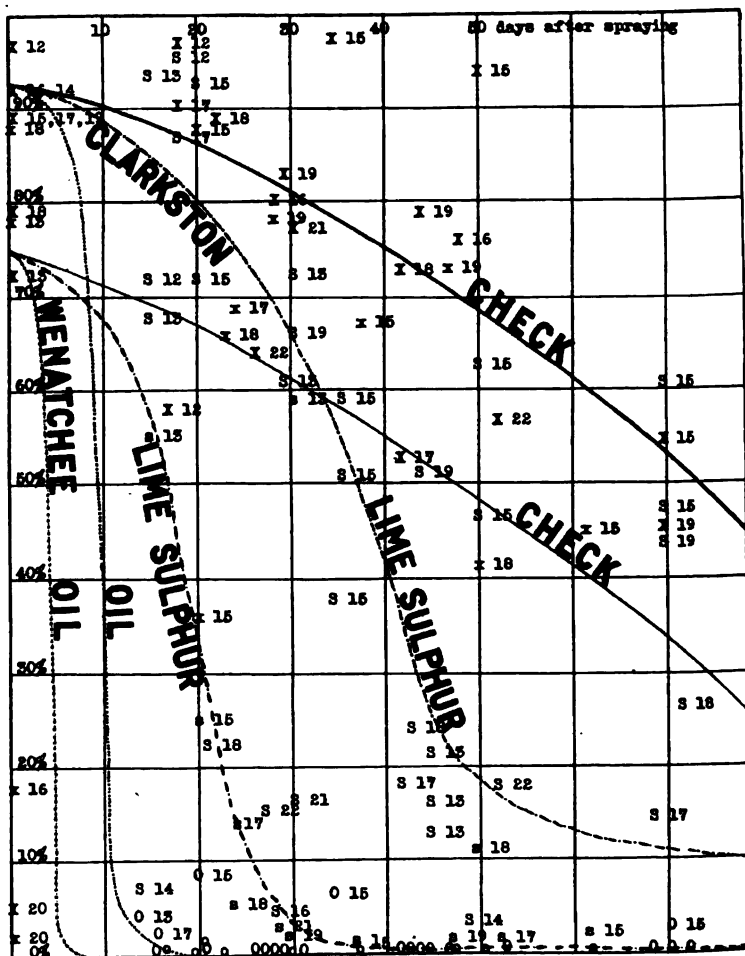
fully grown. The San Jose scale is unable to thrive under conditions at Pullman, although determined efforts have been made to introduce and establish it. Why some Clarkston scales can survive a strong bath of lime-sulphur, but all die when brought to an upland locality, is one of the strange happenings of Nature.

EXPLANATION OF PLATE

- A. Oval male and circular female scales.
Not Sprayed. Photographed April 19.
- B. Clarkston scales photographed seven weeks after spraying with 10 degree lime-sulphur. The convex scales (x) have grown from the size indicated by the small killed wintering scales (o).
- C. Yakima scales photographed 43 days after spraying with 1: $\frac{1}{2}$:5 lime-sulphur formula. Note that the marked individuals are still growing altho the scale covering is arrested.
- D. Clarkston scales maturing though encrusted with lime-sulphur. Adult males have already emerged from the oval scales. The round scales are nearly full-grown females.



**San Jose Scale on Apple Bark—Enlarged about eight diameters
(For explanation see page 48.)**



EXPLANATION OF CHART

Mortality curves of San Jose scale at Clarkston and at Wenatchee. Height of curve at any point indicates percentage of scale alive. Distance to the right indicates days intervening since spraying. Unsprayed checks and treatments with 3 degree lime-sulphur and 5 per cent oil are indicated.

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STATE COLLEGE OF WASHINGTON
AGRICULTURAL EXPERIMENT STATION
PULLMAN, WASHINGTON

Director's Office

Thirty-Second Annual Report

For the Year Ending June 30, 1922

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*In cooperation with the United States Department of Agriculture

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LETTER OF TRANSMITTAL

Pullman, Washington,
December 19, 1922.

Honorable Louis F. Hart, Governor,
Olympia, Washington.
Sir:

Pursuant to an act of the Congress, March 2, 1887, relating to the establishment of agricultural experiment stations, I have the honor to transmit herewith a report of the activities of the Washington Agricultural Experiment Station for the last fiscal year.

Because of the nature of some of the work, the report in part covers the activities from November 1, 1921 to October 31, 1922, rather than the fiscal year July 1 to June 30. The context indicates where this is the case.

Suggestions as to some of the needs of the station and a financial statement also are included.

Very respectfully,

EDWARD C. JOHNSON,
Director.

THIRTY-SECOND ANNUAL REPORT, WASHINGTON AGRICULTURAL EXPERIMENT STATION

DIRECTOR'S STATEMENT

Introduction

The statement that whatever benefits agriculture is of equal benefit to the business enterprises of towns and cities and that whatever helps the farmer is equally, if not more helpful, to those in other occupations, is now regarded almost as a truism. In fact anything which helps agriculture is being recognized more and more as contributing not only to the welfare of the farmer but of the general public. Largely because of this fact, our legislative bodies provide financial support from public funds for such institutions as the agricultural experiment stations, the Land Grant colleges with their extension service and the departments of agriculture. They regard these institutions as great public welfare agencies whose activities in nowise should be reduced but rather increased in times of public stress. They realize that these institutions are assets rather than liabilities and that funds expended for their support are investments bringing large dividends.

At the same time our legislators and all good citizens interested in the welfare of the people are eager that the work of these institutions be conducted with economy and efficiency so that for every dollar spent there shall be commensurate returns. The public servants in charge of these institutions are equally eager to see this accomplished and are using every effort in this direction. That they are succeeding in a large measure is shown in this and other annual reports and in the increasing confidence and interest of the public in these institutions.

The agricultural experiment station, of which this is the annual report, has attracted more attention during the past year perhaps because of its helpful work and the needs of the times than during any other year in its history. This has been shown not only by the increasing requests for information by letter and in an increasing attendance at extension service meetings, but by many appeals for experimental and investigational work on problems yet unsolved and questions unanswered. Thus during the year there have been urgent requests from the apple growers for investigational work on winter in-

jury and the collar rot of apple trees; from the cranberry growers, on the insects and diseases of cranberries and general methods of cranberry culture; from the strawberry growers, on root weevil; from the dairymen, on contagious abortion and other diseases of cattle; from the irrigation farmers, on cost of production of sugar beets and organization of irrigation farms; and from the market milk producers, on the cost of producing milk.

Many of these requests for investigational work it has been impossible to satisfy because of lack of funds. In other cases some assistance has been rendered by enlisting the help of various offices of the U. S. Department of Agriculture and in still others some work has been made possible by contributions from counties and groups of farmers or organizations.

The U. S. Department of Agriculture, for instance, was appealed to in regard to the winter injury and collar rot of apple trees and sent Dr. M. B. Waite, to go over the situation in the orchard sections of Chelan and Yakima counties, to meet the growers and to discuss with them their problems. The department also responded to a request for a specialist in sugar beet production, who co-operated with the experiment station in an investigation of the cost of production and farm organization in the sugar beet section of the state. Chelan county continued to supply the salary and expenses of an investigator to study cover crops and fertilizers in the orchards of Chelan county under the supervision of the experiment station. The county commissioners of Pacific county appropriated funds, which, in conjunction with a small fund from the experiment station and the extension service, made it possible to undertake one season's investigation and demonstration work in the cranberry section. The Chambers of Commerce of Cheney and Spokane contributed funds towards the salary for two months of an investigator to study the cost of milk production in the Spokane area and Mr. Dan Scott, director of the Department of Conservation and Development, set aside sufficient funds from his department to furnish the salary and expenses for five months of an investigator in methods of clearing logged-off lands.

This help from outside sources re-inforcing the resources of the experiment station made it possible to begin the work mentioned, much of which together with other investigations not yet commenced should be actively prosecuted in the near future.

The experiment station has been established by law to help solve such problems. Already it has rendered outstanding service which was partly reviewed in the Thirty-first Annual Report of this station. The activities for this year, perhaps the most fruitful in helpful results of any year in the history of the station, are briefly summarized in the divisional reports which follow. These reports also show how the experiment station has attempted to meet the requests for new investigational work and for information, in so far as funds will permit,

without jeopardizing the organized program of the experiment station, a program which has been given careful consideration each year and so shaped as to meet some of the outstanding agricultural problems of the state in so far as this is possible with the funds available.

Investigations in Co-operation With the U. S. Department of Agriculture

Investigations in forage crop production conducted in co-operation with the office of Forage Crop Investigations were continued as heretofore at the main station at Pullman, the Adams Branch Station at Lind and the Branch Station at Waterville, but with some reduction in appropriations from the U. S. Department of Agriculture.

Co-operation with the office of Cereal Investigations in breeding wheat for smut resistance at the main station at Pullman and in investigations of the foot rot of wheat was continued.

Co-operation with the Bureau of Entomology in wire worm investigations commenced three years ago, was continued by the Bureau of Entomology, the work being done primarily in the Adams county area with headquarters at Ritzville and Lind.

Investigations in seed potato production in co-operation with the office of Horticultural Investigations were continued, the work being done at Pullman, at the Irrigation Branch Station at Prosser and in co-operation with farmers in Clark, Yakima and Spokane counties.

Co-operation with the Bureau of Agricultural Economics and with the University of Idaho in investigating the cost of producing wheat and the organization of wheat farms in the Palouse country was continued for the third year and the results will be published in the near future.

Co-operation with the office of Sugar Beet Investigations of the U. S. Department of Agriculture in a study of farm organization and cost of producing crops in the sugar beet section was commenced.

On invitation, the office of Western Irrigation Agriculture placed a representative at the Irrigation Branch Station at Prosser to co-operate with the station staff in irrigation studies.

Changes in Staff

E. G. Woodward, head of the Department of Dairy Husbandry, resigned March, 1922, to take up dairy farming in Connecticut and E. V. Ellington of the U. S. Department of Agriculture was appointed as his successor.

J. R. Neller, formerly of the New Jersey Experiment Station, was appointed assistant chemist, August, 1921.

Buildings and Land

A beef cattle barn 140x32 and two wings 50x36, and a sheep barn 100x48 were completed. Two cement silos 14x36 were constructed in

connection with the beef cattle barn and a wooden silo 12x30 in connection with the sheep barn. Lots around the beef cattle barn were filled with crushed rock. Both of these buildings, while serving primarily the teaching work in the College of Agriculture, also are of help in investigational work. The old cattle barn was remodeled somewhat, providing better and more ample quarters for the dairy cattle.

At the Irrigation Branch Station at Prosser, an additional silo, 14x44½ feet and corrals and feeding lots for sheep and cattle were constructed. The farm was fenced rabbit-tight to prevent depredations by rabbits in the experimental plats. The irrigation system was improved and practically completed. At this station there is now great need for a cottage for the superintendent, who at present must reside in town four miles away; a cottage for one of the investigators on the station; a laboratory and seed house; a bunk house for the farm help; a dairy barn, poultry house and a hog house. It is contemplated that all buildings at the Irrigation Station will be simple in type and construction and of such character that any of them may be duplicated by the practical farmer.

At the Adams Branch Station the buildings were given a coat of paint. No additional buildings are contemplated at present.

At the Waterville Branch Station some repairs were made on the old house at the rented farm so as to make it usable for farm help. No building program is contemplated at this station.

In the last two annual reports of the Experiment Station, the need for more land at the State College at Pullman for the growing of pure seeds for distribution to the farmers of the state has been emphasized. The college farm is being used more and more for pasture and for producing feed and forage for the dairy and beef cattle herds and therefore the seed producing area has been reduced. More land is still needed for pasture and forage production while the demand for seeds of improved varieties is beyond the ability of the station to supply. As such varieties are secured by means of breeding, by importation from other countries and other states and by selection, this demand will become the more urgent. In the director's report for 1920 and again in the report for 1921 the following paragraph occurs.

"The college farm, now consisting of about 560 acres, is used for all the experimental work and for the growing of some seed and some feed. There is always more demand for seed than can be supplied. Large quantities of feed also must be purchased each year for the stock on hand, and with the increasing herds and flocks more feed will be needed. It should not be necessary to ship this in and to pay for freight and dealers' profits as well as feed from current appropriations. With additional land on which to increase and grow seed for distribution, the land now devoted to this purpose would be available for necessary expansion of pastures and for feed produc-

tion." It is urgently recommended that provision be made for additional land so that the needs here indicated may be provided.

In connection with the seed work, a seed house with ample storage for the seed handled and thoroly equipped for handling and distributing superior seeds is essential. This is now lacking and should be supplied.

Needed Additions to the Station Staff

That there is much need for additions to the station staff was stressed in the report for 1921. There should be additional specialists devoting full time to investigational work on many urgent cultural, management plant diseases and insect problems of horticultural crops which are of vital importance to this industry and which are not yet solved. Among these the leaf roller, the most serious pest confronting the fruit growers of the state, already well established in the Spokane Valley and spreading to the Wenatchee, the Yakima and the Walla Walla areas; the red spider, a pest which is a menace to tree fruits, small fruits, vegetables and ornamental plants; the collar or crown rot, a disease affecting apple trees in the irrigated sections; soil fertility in orchard and berry fields, believed by many fruit growers to be the most important problem affecting yield, quality and costs; the cultural disease and insect pests of cranberry growing, which are threatening the very life of this infant industry, and the strawberry root weevil which within twenty years has spread to every strawberry district in the state are outstanding examples.

Investigational work is urgently needed on contagious abortion in cattle, a disease affecting from 50 to 75 per cent of the dairy herds of the entire state and many of the beef cattle herds. This problem is so serious not only to the individual dairyman in whose herd the disease is found but to the dairy industry of the entire state that there should be no further delay in undertaking comprehensive investigations looking to its solution. While this may take years of intensive work it is not too early to begin.

Cost of production and farm organization studies have been found extremely useful to farmers in making clear what farm products actually cost the producer and in pointing out the types of farm organization which are the most likely to reduce production costs and, therefore, are very helpful not only in a period of stress such as agriculture is undergoing today but in more normal periods. Some investigational work along this line has been made possible by co-operation with the U. S. Department of Agriculture and by the use of a research fellow in connection with the station. There should be funds, however, so that a full time investigator with the necessary clerical assistance could be employed to take up such studies as the cost of production and organization of fruit farms, poultry farms, general diversified farms in the irrigation belt and problems in connection with land tenure and leasing.

Additional help for investigational work also is much needed in dairying, animal husbandry, farm crops, soils and poultry husbandry. Such help should devote full time to experiment station work so that it will be possible at any time to make the necessary trips to those sections of the state where the problems occur.

Increased maintenance is a necessity in connection with many of the fundamental studies now under way and the investigations to be undertaken. The needs of the various divisions of the station are more fully discussed in the divisional reports.

With the general demand and need for retrenchment, it may seem to some that the State of Washington cannot now afford to undertake more investigations even though they are essential to the welfare of agriculture. In view, however, of the increasing benefits to the state from past investigations such as methods of control of the codling moth and the San Jose scale, the development of the lime sulphur spray, the extension of the use of miscible oil, the vast changes in spraying practice, the adoption of the cover crop system in orchards, the development and use of high yielding varieties of wheat, the betterment of smut control methods, the improvements in tillage practices and soil management resulting from soil experiments, the demonstration of the use of iodine in the control of goitre in domestic animals and improvements in poultry management, and the great importance of the experimental work now under way together with the pressing needs for additional investigations briefly reviewed and stressed in this report, the question is not, will it pay or can the state do this now, but rather can Washington afford not to have this work done?

DIVISION OF AGRICULTURAL ENGINEERING

L. J. Smith in Charge

One of the most important problems of the farmer in logged off areas is the clearing of logged off lands and putting these into such shape that they may be used for agricultural purposes. Almost every farmer in this section has some uncleared land on his place. Many methods of clearing have been tried. Some are better adapted to certain conditions than others. Certain methods are tried at a very considerable expense and found to be failures. In a few years some one else comes along and makes the same mistake, not having the benefit of the experience of those who have gone before.

Thru the co-operation of Director Dan Scott of the State Department of Conservation and Development, the Division of Agricultural Engineering was able to put a specialist in Agricultural Engineering in the field for five months to study methods and costs of clearing logged off lands. He found that a combination of splitting with powder and pulling with gasoline or light steady donkeys often is one of the

quickest and most economical methods of procedure. Many fail to understand the possibility of pulling out stumps with a team of horses and block and tackle. Where the soil has a sufficient amount of clay to allow the root to be well burned out, proper methods of burning were found to be the simplest and cheapest on many farms where more expensive equipment could not be had. Many farmers were found to be unfamiliar with modern methods of burning stumps.

A report of the investigational work which deals with the methods of using tackle for pulling and piling stumps, the use of powder and modern burning methods together with considerable cost data of splitting and pulling was prepared. This has been submitted to the State Department of Conservation and Development for publication.

In connection with the new dust treatment for the prevention of wheat smut, a machine was devised for applying the copper carbonate efficiently and at a low cost. Blue prints of the machine were made for distribution on request to farmers. A patent was applied for in the name of the experiment station to protect those who wish to make their own machines.

Needs of the Division

The logged off problem is so important a one in this state where there are between two and three million acres of logged off land, which, when cleared, will be suitable for agriculture, that it would seem essential for the state to undertake a program of careful investigation to simplify methods and reduce the cost of clearing land in order that it may be brought into productive use.

A maintenance fund for helpful investigations in connection with farm equipment and farm repairs is needed.

DIVISION OF ANIMAL HUSBANDRY

H. Hackedorn in Charge

BEEF CATTLE INVESTIGATIONS

Sunflower Silage vs. Corn Silage for the Production of Beef:

During the 75-day period between December 2, 1921, and February 14, 1922, two fairly uniform lots of grade cattle were fed with the view of comparing sunflower and corn silages in roughage rations of steers. One lot of 13 steers received an average daily ration of two pounds cottonseed meal, 13.2 lbs. alfalfa hay and 39.6 lbs. corn silage per head. The other lot of 12 steers consumed 2.1 lbs. cottonseed meal, 12.4 lbs. alfalfa hay and 43.0 lbs. sunflower silage. The average daily gain for the entire period was the same for both lots, being 1.2 lbs. per steer. No difference in condition could be detected between the cattle fed corn silage and those fed sunflower silage. No trouble was ex-

perienced in getting steers started on sunflower silage, and uniform consumption of this roughage was noted throughout the test.

Producing Registered Beef Cattle Under Farm Conditions:

Two years' data have been compiled concerning the operations of the college beef herd. These records include breeding and calving dates, feed and weight records, length of the pasture season, the area grazed and kind of pasture, the cost of fitting show steers and expenses of showing, sale expenses, etc.

SHEEP INVESTIGATIONS

Lamb Feeding:*

A summary of the first year's work with fourteen lots of fifty lambs each, fed sixty days, was published in Bulletin 170. The work for the coming year is to be conducted along essentially the same lines.

First, Second and Third Cuttings of Alfalfa Hay Compared:*

The first year's results indicate that if first cutting hay is considered as 100 per cent, then second cutting hay is only 63 per cent and third cutting 85 per cent as valuable for fattening lambs.

First Cutting Sweet Clover Hay Compared With First Cutting Alfalfa Hay:*

If first cutting alfalfa hay is considered 100 per cent, then first cutting sweet clover cut for hay at a height of 24 to 30 inches has a value of 123 per cent.

Light and Heavy Grain Rations Compared:*

Five lots were fed respectively one-fourth, one-half, three-fourths, one and one-half lbs. of corn per head daily, with all of the hay that they would consume. The second year's work will be modified to include corn silage in the ration.

The largest returns were obtained with the most liberal grain feeding. The test shows that the cheaper gains do not necessarily return the greater profit because of a lower market valuation of the poorer finished lambs fed the cheaper rations.

The Value of Silage in Lamb Rations:*

The first year's work shows a decided advantage resulting from the addition of one and one-half lbs. corn silage to corn and alfalfa hay rations, for fattening lambs. The addition of cottonseed meal to a corn, alfalfa hay and silage ration, resulted in an increased cost of gains without increasing the value or affecting the rapidity of gains or degree of finish over those lots fed no cottonseed meal: The

*All experiments marked with an asterisk were conducted at the Irrigation Branch Station at Prosser

chemical analysis of the hay used in the experiment showed it to contain 13.44 per cent crude protein which is higher than most Middle West hays.

Beet Molasses Compared With Corn When It Replaces One-Third of the Concentrates:*

Lambs fed .483 lbs. beet molasses and .960 lbs. of corn per head daily made as good gains as those fed 1.354 lbs. corn. The molasses induced a slightly greater hay consumption. The test shows that 135.29 lbs. beet molasses had the same feeding value as 115.89 lbs. corn plus 65.60 lbs. alfalfa hay. The lambs fed corn and beet molasses although making as good gains as those fed straight corn sold at \$.25 per lot less than the corn lot because of a slightly lower finish.

Flock Records:

Records of the management of a flock of 50 ewes under farm conditions have been kept for two years and are being continued. The data include feed, weight, shearing, sale and cost records.

SWINE INVESTIGATIONS

Comparative Value of Protein Supplements in Swine Rations:

A summary of the last three years' work was published as Bulletin 170 of the regular series. Some of the outstanding findings follow:

Fishmeal and digester tankage have, from a practical standpoint, an equal feeding value.

Cocoanut meal can be successfully substituted for millrun in hog rations. It is not a satisfactory protein supplement when used alone.

Linseed meal does not produce as big and as economical gains, nor as satisfactory growth as tankage and fishmeal, when used to supplement barley mixed with one-third its weight of millrun.

Mixtures of linseed meal with either tankage or fishmeal, have no apparent advantage over either tankage or fishmeal, but they do produce better results than linseed meal alone.

Cane molasses was equivalent in feeding value, pound for pound, to barley, when fed on pea forage, when used in replacing only one-half of the barley in the ration. It did not prove as efficient when fed in dry lot, nor when substituted for one-half of the barley in the ration at the rate of one and one-half pounds of molasses for one pound of barley.

Peas yielding 15.5 to 17.0 bushels per acre, pastured off by hogs produced 145.8 to 222.9 pounds of pork per acre. In general, the grain saved by producing the pork on pea forage, as compared with dry lot was practically equivalent to the yield of peas. This with the labor saved in harvesting the peas, as well as the advantage of increasing soil fertility, recommend peas as a practical forage crop for hogs under Eastern Washington conditions, wherever the rainfall is sufficient to grow peas successfully.

An acre of alfalfa which yielded approximately two tons of hay

the first cutting, produced during the remaining part of the summer and fall, when pastured, from August 11 to October 15, a total of 81 pounds of pork.

Herd Management:

One year's records have been completed on the work outlined to compare the results of two systems of swine management, one in which the pigs are to be farrowed during early March and the other during the latter part of April.

The Value of Wheat Stubble for Fattening Pigs:

Hogs turned into a wheat stubble field, which was rated as having more than the average amount of short heads and shattered grain gained only four-tenths pound per head per day. The area per pig was three and a third acres and 4.62 pounds of pork was produced per acre. If conditions had permitted, the stubble would have furnished feed for 20 to 30 days longer.

The Feeding Value of Millrun and Alfalfa Hay in Rations for Growing Pigs:*

The results from two lots of fall farrowed pigs, fed in this experiment indicate that for growing breeding stock, fine leafy first cutting alfalfa can be substituted for millrun. The ration containing the millrun was more satisfactory for hogs to be marketed as fat hogs.

DIVISION OF BACTERIOLOGY

W. L. Nightingale in Charge

Legume Culture Work:

In co-operation with the Department of Farm Crops, 6,191 acres of inoculation culture were distributed among 795 farmers since January 1, 1922.

Factors That Control the Infection of Legumes by Bacteria:

Work was continued in the greenhouse on this project and about 300 total nitrogen determinations were made in the laboratory from samples taken in last year's work. These analyses cover the plants which were in the greenhouse. Samples of plants taken in the field are now ready to be analyzed. Data were taken on the virulence and efficiency of 34 different strains of *B. radicola* last year and this year the work was duplicated and extended to include 40 different strains of *B. radicola*. Many of these strains were secured from

other experiment stations and compared with strains secured at or native to the vicinity of Pullman.

This year's greenhouse work has been completed and the data taken will be sufficient for completing this project. The data at present compiled show interesting and practical variations in the efficiency of the various strains of bacteria under way.

Effect of Sunlight on Longevity of *B. Radicicola* Applied to Legume Seeds:

An experiment was started in March, 1922, and data periodically taken since that time to determine the necessity of keeping seeds away from sunlight after they have been artificially inoculated. Growers have been advised in the past that it is imperative to keep the seeds away from sunlight in order to prevent the destruction of the bacteria applied to them. It has even been advocated that seeding should be done on cloudy days in order that the sunlight might not kill the bacteria. Data have been taken on four different varieties of common legume seeds planted in this state, showing that the bacteria applied are not all immediately killed by exposure to sunlight. A very high percentage, however, are found to be killed during the first few days exposure. From that time on appreciable numbers have been found to remain alive on the seed after four months exposure to sunlight.

This work promises to give very interesting and practical results and will be continued.

The Effect of Various Factors on Inoculation With Legume Bacteria:

A small amount of work was conducted on this project. Field work in co-operation with the county agent of Franklin county on new land, old land that had previously grown legumes and on land that had never grown legumes, will give comparative results of the value of inoculation in that county.

Soils from Snohomish, Grays Harbor, Kittitas, Lewis, Kitsap and Adams counties were under study in the greenhouse. Data were secured on the presence of *B. radicicola* and the effect of chemical stimulation upon the growth of legumes in these soils. Comparisons were also made in the greenhouse and in the field on three different kinds of commercial cultures and the pure cultures made at this station.

Vinegar Culture Work:

This work is being carried on as a new phase of experiment station service and 116 farmers were supplied with 172 cultures. A pamphlet on how to make cider vinegar was prepared and is distributed to vinegar makers with a complete set of instructions for the use of pure cultures.

Some experimental work was carried on throughout the year on different varieties of apple juices to study the problems of vinegar making and to test out the efficiency of the vinegar cultures.

DIVISION OF CHEMISTRY

J. L. St. John in Charge

Nutritive Value of Wheat:

The study of the limits for the need of inorganic elements in a wheat ration has been continued and results on the optimum and maximum limits in the use of sodium have been obtained. The ration containing one-half per cent of the element sodium has proved very successful and a ration containing .3 per cent also gave successful results. The optimum evidently lies between these two and .35 per cent of this element in the ration seemed to give the best results when growth, reproduction and general condition of the experimental animals are considered. Over one per cent in the ration gave very unsatisfactory results, as had a ration containing no added sodium. In addition to the effect of such variation of this element on the growth and reproduction of the animals, it has been noted that a proper salt adjustment also permits a much more economical use of feed. This work is nearly ready for publication.

A study has been made of the effect of the variation of chlorine. Although this work has not been completed, it seems to show that it is necessary to add chlorine to such a wheat ration for a successful rearing of the experimental animals. Work is being continued to confirm this point and to establish the optimum and maximum limits for the need of this element.

Work has been started on the value of the element potassium in a wheat ration and the very limited amount of data so far obtained indicates that potassium may replace sodium in such a ration.

A comparative study is also being made of the actual nutritive value of different wheats and the flour produced from these wheats. The higher nutritional value and economy of wheat over flour is noticeable and the hard wheat proved to be of greater value than the soft wheat.

Sulfur As a Plant Food:

Work was resumed on this project last year and this has been continued. Through laboratory, greenhouse and field results it is hoped to determine the place of various forms of sulfur in a system of permanent agriculture. Data obtained during the year indicate that the application of elemental sulfur at the rate of 160 and 500 pounds per acre causes an accumulation of soil nitrates while a 1000 pound application causes a decrease. Nitrate accumulation was decreased by the use of sulfur on manured soils. Sulfur oxidized fairly rapidly in the soils tested and the rate of oxidation was affected but little by the addition of manure. The rate of oxidation of sulfur applied at the rate of 500 pounds per acre seems to be about the same in Palouse and Lind

soils. Palouse soil seems to contain more soluble sulphate than Lind soil. The application of a moderate amount of both gypsum and elemental sulfur caused an increase in some cases over the smaller alfalfa and clover on Lind and Palouse soils. The increase obtained from the Lind soil was much larger than from the Palouse soil, the increase being striking in the case of clover on the former where the applications increased the yield to four and five times that of the check pot. The application of 1000 pounds of gypsum and 500 pounds of elemental sulfur caused an increase in some cases over the smaller application while in other cases the yield was less than in the check pots. Treatment increased the protein content of the legumes grown on the Lind soil considerably more than those grown on the Palouse soil.

Measurable Characteristics of Maturing Fruits:

Work has been started on this project in co-operation with the Horticultural Division under Adams funds. Methods are being worked out and some data have been collected on the changes occurring during ripening.

Baking Qualities of Flour:

The study of the action of enzymes on various flours is being continued in order to obtain more information on the quality of various gluters.

Co-operative Study of Methods of Analysis:

The Association of Official Agricultural Chemists is actively pursuing a study of various methods of importance to agricultural chemists. It has been possible for the division to co-operate in this investigation by work on different methods for the determination of fibre in feeding stuffs and the determination of arsenic in several different spray materials.

Service Work Within the Station:

Chemical help on projects under way in other divisions of the Experiment Station is much needed. The division has endeavored to do as much of this work during the year as possible. Analyses have been made of a variety of samples for the Veterinary, Bacteriology, Horticultural, Animal Husbandry, Dairy Husbandry, Poultry and Entomology Divisions of the Station.

Miscellaneous Service Work:

Samples of foods have been analyzed for the purchasing department at Olympia. A large number of miscellaneous samples are received during the year which cannot be handled because of lack of chemists and funds. Such samples include feeds, water, spray materials, samples in cases in which poison is suspected, etc. It is necessary to charge a fee for analyses of such samples.

State Chemist

A large part of the duties of the Chemistry Division are in connection with the enforcement of the pure food, feed, fertilizer, insecticide and fungicide laws of the state. This work is done in co-operation with the State Department of Agriculture and analyses made of official samples received from the inspectors of that department. The number of samples received has been several times larger than in previous years.

Over one-fifth of the samples of feeds and fertilizers received have proved grossly illegal and many others illegal to a lesser extent and less than one-half of the brands of feeds and fertilizers registered in this state have been inspected. The need for a large expansion of the work, therefore, is evident. In connection with the fertilizer inspection it would also be highly desirable to check up the availability of the fertilizer elements in addition to determining the total amount present.

Many samples of foods, dairy products and spray materials were received and in several cases striking violations of the law were noted. An insignificant number of such samples are handled in comparison with the need. In a state in which horticulture is important, spray materials should be carefully checked. The purity of foods is of interest to everyone.

A special fund should be available with which the State Chemist and the State Department of Agriculture might handle the work of protecting the people of the state against fraud and carelessness in the manufacture of products which are sold to the consumer. This could be raised either by direct legislative appropriation or by a tonnage and tag tax, the proceeds of which should be used for this purpose. The latter method is preferable as it involves no increase in the expense of the state, and places the expense on those directly benefited. This fund should not only cover the salaries and expenses involved in this work but should also permit the State Chemist to publish the results of the work done. The use of such results by the consumer in the purchase of his supplies would be an effective weapon in the enforcement of the law. The results obtained this year are ready for publication.

Needs:

This Experiment Station has been working on the development of a smut resistant wheat for some years. A careful study of the fundamental difference between smutting and smut resisting wheat would be of much value. The preparation of a substitute for the expensive nicotine sulphate spray would be of great economic importance as would

the preparation of a spray for combating the leaf roller. The chemistry of the various sprays in use at present should be thoroughly studied. Methods for the utilization of fishery by-products should be investigated. Definite methods of classification of fish and meat meals to determine whether they should be used for feed or fertilizer should be worked out. Fundamental questions of nutrition should be investigated including a further study of inorganic salts. Results obtained would be of great value both in human and animal nutrition. Further co-operative work with other divisions should be undertaken. A problem in poultry feeding is calling for attention. The failure of ciders to produce vinegar of the required strength should be investigated. A standard for various foods including some canned goods and ice cream mixes should be worked out.

From the facts previously mentioned, it seems evident that the work of the state chemist should be greatly expanded. With additional funds from a tonnage and tag tax, the inspection work of the State Department could be expanded and made more effective and several men added to the laboratories of the state chemist to handle the samples collected. Such additional work would be a great economy for the state.

DIVISION OF DAIRY HUSBANDRY

E. V. Ellington in Charge

A Study of Calf Rations:

A study of calf rations has been in progress for the past three years. In this investigation comparisons were made of certain prepared calf meals, home-made calf meals, condensed buttermilk, powdered skim milk and whole milk as a feed for growing calves.

Thirty-five calves were used in these experiments, ranging in age from two to three weeks to four to six months.

The following table is a summary of the results:

	Condensed Buttermilk	Powdered Skim Milk	Whole Milk	Skim Milk
No. of animals.....	8	3	2	11
Av. No. days on experiment.....	149.125	79.33	105.	134.63
Av. gain in weight per day, lbs.....	1.436	.966	1.242	1.674
Av. gain in height at withers per calf per day, inches.....	.0677	.029	.0728	.0663
Av. gain in chest measure per calf per day, inches.....	.1119	.096	.1157	.113
Av. amt. feed per calf per day, lbs.	3.557	1.470	8.88	10.33
Av. amt. grain per calf per day, lbs.	3.387	1.923	1.623	3.714
Hay	Alfalfa	Hay	Ad. Lib.	

	Calf Meal No. 1	Calf Meal No. 2	Home Mixed Calf Meal
No. of animals.....	4	2	5
Av. No. days on experiment.....	142.5	120.	114.6
Av. gain in weight per day, lbs.....	1.122	1.383	1.457
Av. gain in height at withers per calf per day, inches.....	.0563	.0579	.0659
Av. gain in chest measure per calf per day, inches.....	.0969	.0870	.1004
Av. amt. feed per calf per day, lbs.	1.225	2.07	1.656
Av. amt. grain per calf per day, lbs.	2.884	2.819	3.032
Hay	Alfalfa Hay Ad. Lib.		

The calves raised on these rations were taken from their dams within 24 hours after birth and were then fed whole milk until they were ten days to three weeks old. At that time the experimental ration was gradually substituted for the whole milk, a week to ten days being used to make the change. After this period no whole milk was fed.

All the calves were allowed access to water and salt at all times and alfalfa hay was kept continually before them. They received a standard grain mixture consisting of 100 pounds of rolled barley, 100 pounds of rolled oats, 100 pounds of mill run and 100 pounds of linseed meal. The home mixed calf meal used consisted of a mixture of 40 pounds of finely ground corn meal, 20 pounds of finely ground alfalfa leaves, 20 pounds of mill run and 20 pounds of linseed meal. Two pounds of this mixture was scalded and stirred into enough warm water to make a gallon of liquid which was considered equal to a gallon of milk.

While the skim milk calves made slightly greater gains per day, they were followed very closely by those on home mixed calf meal and condensed or semi-solid butter milk. It was noted that the calves raised on milk substitutes had approximately as great a body growth as those raised on milk, but the former appeared more rough and carried a longer coat of hair than the latter. It was somewhat more difficult to change calves to the various meals than to skim milk without causing scours. In no case, however, did the animals refuse to eat the meal and in nearly all cases they would eat too much if given a chance. After the change had been completed there was practically no danger of scours. All of the calves raised on condensed butter milk made satisfactory gains, averaging 1.43 pounds per day. While the gains the first two months usually were less than these figures, at a later age the growth was more rapid. The calves fed condensed butter milk were not troubled with scours.

Only three calves were fed skimmed milk powder. These were all of one breed, namely, Jerseys. Consequently this test is not as inclusive as the condensed butter milk test. The calves made an average gain of about one pound a day for the period of 80 days.

The Effect of Exercise and Feed Upon the Vitality and Breeding Ability of Bulls:

The work reported in the 29th and 30th Annual Reports was continued. The additional results seem to reinforce the evidence that in the case of slow bulls exercise greatly diminishes the time required for service.

In the examination of the samples of semen taken from the cows after service from a bull that had exercised, the spermatozoa were more vigorous than if exercise had been lacking. This was evidenced by the fact that they were motile for a longer period than was the case when the bulls were kept in box stalls without exercise. With exercise some motion of the spermatozoa was noticeable 22 to 39 hours. Without exercise motion ceased in from 3 to 24 hours.

Official Testing:

One hundred and six breeders did testing during the year November 1, 1921, to November 1, 1922.

The average number of herds tested per month was 68 and the average number of cows, 421.

This is an average of six cows per herd or the same as for the previous year.

Averages by Breed

Ayrshires	2 herds per month.....	with 12 cows
Guernseys	11 herds per month.....	with 39 cows
Holsteins	28 herds per month.....	with 204 cows
Jerseys	27 herds per month.....	with 160 cows
Shorthorns	1 herd per month.....	with 7 cows

The total number of tests conducted was 5,049. For the previous year 4,914. The total number of semi-official tests conducted was 4,678, an increase of 4 per cent over the previous year. The total number of seven day tests conducted was 394, a decrease of 2 per cent from the previous year. The total number of retests conducted was 81, an increase of 5 per cent over 1920-21. There were 17 verifications and 49 check tests.

Three world's records were completed during the year.

Tyee Hiske Fayne, No. 401969, a 4-year-old Holstein, owned by Elmer E. Heg and Sons of East Stanwood, broke the world's milk record for all ages in the 305 day division by producing 25,213.4 pounds of milk in 10 months.

Pieterje Mutual Fobes, No. 428964, broke the 305 day milk record in the Junior 3-year-old class. She is owned by Thos. J. Owens of Kirkland. Her record is 21,368.3 pounds of milk.

Edna of Mt. View, a Senior 4-year-old Guernsey cow has just

completed a world's fat record for her class. She produced 933 pounds of fat in 365 days. She is owned by Wallace and Fordyce of Sunnyside and is the tenth Washington cow to hold a world's record.

Needs of the Division of Dairy Husbandry:

More help is urgently needed on the staff of the Dairy Division. At the present time only a very limited amount of time on the part of the Head of the Division is available for investigational work and the details of such work must be handled by senior students. This should be remedied and funds provided for additions to the staff.

DIVISION OF ENTOMOLOGY

A. L. Melander in Charge.

San Jose Scale, codling moth, leaf roller, spray poisoning of bees, cranberry fire worm and soil treatments for subterranean insects were the subjects of the year's investigations.

San Jose Scale:

In continuation of the spraying experiments in progress for twenty years, tests were made at Clarkston of the relative efficiency of various insecticides used for San Jose Scale. Two examinations of the effects of the spraying were made at intervals of 26 and 52 days after the spraying. At the time of these examinations a varying percentage of living scales was found, the data being summarized in the following columns. In this table are presented the materials used, the concentrations employed, the total number of insects examined and the per cent found alive. For the particularly resistant scales found at Clarkston no dependence can be placed upon sprays based on sulphur, no matter at what concentration they are employed. Some brands of miscible oil are less effective than others, due either to insufficient heavy oil or insufficient emulsifying agents in their composition. A complete report of the experiments on the San Jose Scale is ready for the press and will appear shortly as Bulletin 176.

Spraying for San Jose Scale, 1922

Treatment	Interval 26 days		Interval 52 days	
	Total	% Alive	Total	% Alive
Lime Sulphur 12.....	1277	12.8	1133	9.2
Lime Sulphur 8.....	1047	10.1	328	12.2
Lime Sulphur 5.....	1405	29.0	1160	20.9
Lime Sulphur 3.....	409	16.4	501	21.2
Lime Sulphur 1:½:5.....	1287	21.3	989	15.0
Lime Sulphur 1¼:½:5.....	1183	27.8	567	18.0
Dry Lime Sul. 30:50.....	1019	20.8	1197	17.2

Spraying for San Jose Scale, 1922—(Continued)

Treatment	Interval 26 days		Interval 52 days	
	Total	% Alive	Total	% Alive
Dry Lime Sul. 15:50.....	.....	.....	1130	14.6
Barium Sul. 30:50.....	1089	19.1	1344	23.4
Barium Sul. 15:50.....	1523	19.5	593	14.5
Lime Sul. 5 caseinate.....	1157	20.0	968	17.2
Lime Sul. 3 caseinate.....	1142	20.5	538	13.7
L. S. 3 Casein oil 5%.....	772	3.4	384	1.5
Dormoil 6	1239	0.0	.....	.....
Spramulsion 10	1181	0.0	.....	.....
Spramulsion 6	1435	0.0	1121	0.6
Scalecide 6	1300	0.0	.....	.....
Ortho Oil 10	1202	14.4	1278	21.3
Ortho Oil 6	1130	19.5	1225	18.1
Keresol 10	1196	14.2	960	13.7
Keresol 6	1182	52.2	888	39.4
Check	394	63.7	2223	57.4

Codling Moth:

The main purpose of the codling moth investigation for the year was to determine the value of spreaders. The usual treatment of four sprayings was given a commercial orchard near Spokane. The material used, the number of apples examined, the amount of worminess and the coefficient of efficiency are given in the following table for the Winesap part of the orchard. The last column refers to the quotient found by dividing the total number of worms by the number of stings. It is presented as a means of comparing treatments, in addition to the amount of worminess for each block of trees. While the spraying kept the entire orchard so free of worms that it is difficult to draw final conclusions among treatments, all of which are effective, it will be observed that the omission of a spreader did not detract from the insecticidal value of an application and that doubling the usual strength of lead arsenate gained nothing. However, the fruit sprayed with a spreader, whether casein, soap or glue, showed less blotching of spray and would require less wiping to pass inspection for poison, than fruit sprayed with lead arsenate alone.

Spraying for Codling Moth, 1922

Material	Apples Examined	% Worms	Ratio worms to Stings
Lead Arsenate 8 lbs.....	5865	.34	.039
" " 4 lb. rod.....	7855	.69	.061
" " 4 lb. gun.....	5322	.67	.039
" " 4 lb. syrup.....	5827	.34	.030
" " 4 lb. glue.....	5833	.94	.076
" " 4 lb. Stecho.....	6028	.79	.059
" " 4 lb. 3 S.	4616	.65	.048
" " 4 lb. Kayso.....	5430	.66	.048
" " 4 lb. Soap.....	6201	.50	.039
Check	314	11.40	1.153

Leaf Roller:

Three different points of attack were tried on the orchard leaf roller so alarmingly prevalent in the Spokane Valley. Eggs were sprayed with various oils just before the budding of the trees, larvae just hatched were sprayed or dusted with contact insecticides, and the foliage was kept coated with arsenical in connection with the codling moth treatments in order to reach older larvae. Of these treatments the oil sprays give by far the greatest promise of control, although complete destruction of the embryos was not attained by any materials used. The best results were had with oils at 10% strength although there was much difference in the relative efficiency of the several different brands as indicated below.

Oil Treatment, Leaf Roller Eggs, 1922

Material	% Not Hatching
Ortho Oil 12%	74.
Spramulsion 10%	77.
Scalecide 10%	88.
Dormoil 10%	92.
Dormant Soluble 10%	93.

Various contact insecticides were tried against very young leaf roller larvae. None of these proved at all efficient; from 40% to 100% of the larvae afterwards were still alive and apparently unharmed. Among the materials tested were dusts of tobacco fortified with various admixtures of nicotine extract, Calispray dust, and liquid sprays containing nicotine sulphate or derrisine.

Arsenate of lead, 4 lbs. or 8 lbs. to the 200 gallon tank, used alone or baited with corn syrup, failed to check maturing larvae. There was a slight difference in favor of the extra strength of lead but perhaps not enough to warrant the double cost.

Details of the leaf roller experiment appear in Bulletin 172, recently published.

Soil Treatment of Subterranean Insects:

Under this heading a new project has been formulated and preliminary work was begun the past season. At Walla Walla several soil fumigants were placed underground in an old orchard and a few days later the nearby soil was carefully sifted for insects. In no case did the insecticides manifest long-range effects, dead insects being found only within a radius of a foot or so from the point of administration. Sodium cyanide in powder and solution, Calcium cyanide, carbon disulphid, ground tobacco, nicotine solution and paradichlorobenzene were tried.

Carbon-disulphid fumigation under cover was tried on the large vine weevil, "*Otiorrhynchus sulcatus*" in cranberry bogs at Ilwaco and on its smaller relative, "*O. ovatus*," in strawberry fields at Marysville. Even where as much as 2 oz. was used to every four feet only negative results were obtained.

Cranberry Fireworm:

In co-operation with the Extension Service and Pacific County, information was secured regarding possible means of control of the cranberry fireworm. Experiments conducted at the Cranberry Laboratory, Ilwaco, gave uncertain results from fumigation with cyanide-gas. The cranberry plants held the cloth cover away from the ground, thus permitting dispersion of the gas. Spraying eggs with a miscible oil gives promise of almost complete extermination with no serious harm to the plants. Unfortunately it was impossible to apply this treatment sufficiently early in the season to obtain full information regarding safety and control. Spring growth was well along when the oil spraying was given so that blossom buds were largely destroyed. The plants, however, clearly showed the stimulating effects of the oil and because of freedom from fireworm made conspicuously better growth than on any of the other experimental plots. The next season these plants should outstrip the others in berry production.

Spray Poisoning of Bees:

To find some material repellant to bees that could be added to arsenical sprays, experiments were conducted on fruit trees in blossom and later in an orchard having cover crop of blossoming alfalfa. Dormant Soluble oil, Milkol, Creosol, Nicotine sulphate, butyric acid and crude pyroligneous acid were tried in the first test, enumerated in the order of effectiveness. Even water deterred the bees from frequenting the blossoms, acting as a positive repellent for a short time. Bees ceased frequenting the alfalfa cover crop immediately after nicotine sulphate was added to the arsenical applied to the orchard.

Some Needs of the Division:

Fruit growers and farmers have been asking for investigational work on insect and other pests far in excess of possible accomplishment without additions to the staff. To meet these demands in so far as possible, there should be at least one additional entomologist that could devote his entire time to these problems.

The more pressing demands which should be considered include studies on red spiders of orchards and smaller fruits, root maggots of vegetables, oystershell and cottony scales, wireworms of gardens and grain, woolly aphid of the apple, cutworms and armyworms, cherry fruit worms, prune borers, stem maggot of wheat, and destructive rodents, on none of which is any experimental work now being conducted. Increased time should be available to permit a thorough investigation of the destructive orchard leaf-roller, the strawberry root weevil, the insects of the cranberry bogs, and the newer aspects of control of codling moth, San Jose scale and aphids. The rapid spread of the introduced European earwig and satin moth and the

eastern squash bug, potato beetle and Hessian fly are in need of attention. Information is greatly needed regarding the use and possible injurious effects of oil sprays and of summer sprays, the application of spreaders in both dormant and summer use, substitutes for expensive nicotine, the incorporation of baits or lures with sprays, the most efficient strengths of arsenical and other sprays, the deleterious effects of over-spraying, and the application of soil insecticides.

More library funds are also urgently needed in order to enable the securing of sets of essential periodicals as well as standard reference works. With wide-spread interest in honey production and constant requests of bee-keepers for assistance the time has arrived when an apary should be established to serve jointly the Experiment Station, the college and the Division of Apiculture.

DIVISION OF FARM CROPS

E. G. Schafer in Charge.

Varietal and Cultural Experiments:

The number of varieties of cereal crops being tested has been reduced and the investigations on date of seeding have been extended. This work formerly done in the field only is now also being done in the cereal nursery. Six rates of seeding spaced at six and twelve inch intervals are planted on the first and 16th of August, September, October and November.

The following are some of the results noted in connection with the investigations of this project: The average yield of Turkey was two bushels more than Kanred in 20 trials extending over a period of four years. Victory oats, Washington Number 1187, in a five year average (1916 to 1921) produced 66.7 bushels or 1.1 bushels less than Banner, the leading variety at the Experiment Station at Pullman. The hybrid Turkey x Florence, Washington Number 2324, a variety of winter wheat immune to smut and developed in this nursery during the last six years, was grown under field conditions for the first time.

Distribution of Seed and Bacteria Culture:

The grain storage facilities destroyed by the storm during 1920 have not been replaced and the seed distribution work is being handled with considerable difficulty. However, 25 tons of pure seed were distributed among 88 farmers, representing 20 counties of the State.

Two hundred and fifty-five small lots of seed were sent out for educational and experimental purposes. In co-operation with the Division of Bacteriology, bacteria culture sufficient for the inoculation

of 6443 acres was distributed to 935 persons and was sent to every county of the State.

From over 2000 rows of varieties and hybrids of wheat tested for smut resistance, the following conclusions may be drawn: 1. Most wheats are susceptible to smut, often producing less than 10 per cent of normal heads when planted under conditions favoring infection. 2. Many are intermediate, producing from 20 to 80 per cent of normal heads under the same conditions. 3. Four varieties (Smutproof, Martin Amber, Red Hussar, White Odessa) are entirely immune to smut. 4. Smut resistance is heritable but induced by multiple factors in crosses of Marquis x Turkey, Triplet x Turkey, Hybrid 128 x Turkey, Fortyfold x Turkey, and Turkey x Florence.

Wheat smut was found attacking rye and rye-wheat hybrids. Comparative sterility is being studied in interspecies crosses of wheat and oats.

An analysis of hybrids between Turkey and Jenkin wheat in the second generation indicates that the horny endosperm of Turkey is transmitted as a unit character, the segregation taking place in the heads of the F1 plants.

Forage Investigations:

The forage nursery includes selections and varieties of alfalfa, clover, peas, beans and grasses for determining yields and comparative values.

Observations indicate that all the strains of alfalfa in the test plots have survived the past two winters, and that the second cutting of alfalfa can not be depended upon to furnish hay or seed. Hubam, annual sweet clover in the vicinity of Pullman, apparently does not produce as much forage as the first year's growth of the biennial sweet clovers.

In two years, results in growing sunflowers at different distances apart, the rows three and one-half feet apart gave greater yields of both silage and seed than closer rows, while there was practically no difference in yield when plants were spaced one, one and one-half and two feet apart in the row.

The silage experiments conducted for the last three seasons demonstrated that sunflowers far outyielded corn in this section of the State.

Biennial sweet clover, for pasture in this region of moderate rainfall stays green late in the fall the first year and makes abundant growth early in the spring of its second year so that if two fields are maintained, one seeded each year, pasture may be had thruout almost the entire growing season.

Crop Rotations:

Sunflowers have been introduced into the rotation field as this crop gives promise of becoming an important silage crop. Sunflowers will take the place of vetch which is handled with difficulty

in the rotation field. Other rotations in this experiment are being continued according to the original plan.

Needs of the Division:

The Division of Farm Crops is in need of seed storage for the handling of seed grain. Storage room should be provided for storing fairly large amounts of several superior varieties of grain for distribution and small amounts of a considerable number of varieties for experimental purposes. Equipment should be installed for cleaning, grading, weighing, sacking, fumigating and treating seed of various kinds. Equipment should also be provided for drying and storing seed corn.

The threshing machine and certain other equipment for handling field plots is practically worn out and should be replaced.

Experimental fields should be established in different parts of the State to determine the adaptability of crops and varieties. The main need for this work is additional funds.

DIVISION OF FARM MANAGEMENT

George Severance in Charge.

The Cost of Milk Production and Dairy Farm Organization:

In the fall of 1920, records of the preceding year's business were secured from 91 dairy farms maintaining 1502 cows which produced 10,148,381 pounds of milk. In the fall of 1921 records were secured from 81 dairy farms maintaining 1469 cows which produced 10,341,074 pounds of milk. This work was done in co-operation with members of Dairy Associations in Whatcom, Snohomish, Pacific and Wahkiakum Counties. Two years' records have been tabulated and published as Bulletin 173.

The average production of milk per cow for the two years by counties was as follows: Whatcom, 7942 pounds; Snohomish, 6864 pounds; Pacific, 5568 pounds, and Wahkiakum, 6328 pounds. The average production of butter fat per cow per year for the two years was: Whatcom, 345 pounds; Snohomish, 297 pounds; Pacific, 251 pounds, and Wahkiakum, 319 pounds.

The average quantities of ingredients fed per cow per year with all counties averaged were as follows: Grain 1218 pounds, hay 2635 pounds, succulents 3246 pounds, pasture 214 days and man labor 158 hours. The average net cost of production per cow per year by counties was as follows: Whatcom, \$223.47; Snohomish, \$203.19; Pacific, \$156.77; Wahkiakum, \$170.27. The average cost of producing 100 pounds of milk by counties was as follows: Whatcom, \$2.81; Snohomish, \$2.96; Pacific, \$2.81; Wahkiakum, \$2.68, and the weighted average of all counties was \$2.84.

The cost of producing milk on individual farms varied from \$1.94 per 100 pounds to \$4.39 per 100 pounds in 1919 and from \$1.81 per 100 pounds to \$4.56 per 100 pounds in 1920. In 1919 a price of \$3.40 per 100 pounds of milk would have covered the cost of producing 85% of the total milk produced by the herds studied. In 1920 a price of \$3.40 per 100 pounds of milk would have covered the cost of producing 90% of the total milk produced by the herds studied.

The basic requirements of feed and labor for producing 100 pounds of milk as determined in this study are as follows: Grain 17.7 pounds, hay 38.2 pounds, succulents 47.1 pounds, pasture 3.1 days and man labor 2.3 hours. The total value of these basic requirements equal 75.52% of the net cost of producing milk, feed costing 50.22% and labor 25.30%.

The studies indicate that the cost of producing milk may be materially reduced by the use of better stock, by better feeding and by better labor management.

Studies on Cost of Wheat Production and Grain Farm Organization in the Palouse:

The field work on the three year study on the cost of wheat production and grain farm organization in the Palouse conducted in co-operation with the Office of Farm Management of the United States Department of Agriculture and the University of Idaho was completed in the summer of 1922. The Office of Farm Management tabulated the records secured in the summer of 1921 and issued a mimeographed report of the first two years' farm records, 1919 and 1920. The office is now preparing the three years' records, 1919, 1920 and 1921 for publication. Usable records were obtained from 229 representative farms located near Pullman, Washington, and Moscow, Idaho, about an equal number in each State in 1919 and from 241 farms in 1920. Of the farms studied for 1919, 105 were operated by owners, 71 by tenants and 53 by men who owned some land and rented an additional area. Of the farms studied for 1920, 107 were operated by owners, 86 by tenants and 48 by men who owned some land and rented an additional area. As far as possible, records from the same farms were taken each year but for various reasons a number of the records could not be taken the second year, hence a number of new records were secured.

The averages of the size of farms from which records were secured were as follows: In 1919, farms operated by owners, 297 acres, tenant farms 312 acres; in 1920, farms operated by owners, 331 acres, tenant farms 334 acres. The average investment on the farms studied was as follows: In 1919, \$45,978 for farms operated by owners and \$4596 invested by tenants on tenant farms; in 1920, \$52,192 on farms operated by owners and \$4585 invested by tenants on tenant farms. In 1919, owners operating their own farms made

an average labor income of \$1766. In 1920 they made an average labor income of minus \$1815. In 1919, tenants made an average labor income of \$2420 and in 1920 \$206. The labor income is the net return left the operator for his service after paying all expenses including interest on investment, labor performed by other members of the family, depreciation and any decrease in inventory. A minus labor income of \$1815 means that the operator not only had nothing left to pay for his own service but lacked \$1815 of paying expenses, including interest on investment, depreciation on buildings and equipment and pay for the labor performed by other members of his family.

The 1919 records represent 19,128 acres of winter wheat yielding 554,420 bushels or an average of 29 bushels per acre and the 1920 records 15,610 acres of winter wheat yielding 514,272 bushels or an average of 33 bushels per acre and 10,983 acres of spring wheat yielding 220,264 bushels or an average of 20 bushels per acre in 1919 and 17,407 acres of spring wheat yielding 426,144 bushels or an average of 24 bushels per acre in 1920. The following table shows the average cost and range of cost per bushel for winter wheat and spring wheat in 1919 and 1920 on owner farms and on tenant farms.

Crop	Owner Farms—1919		Tenant Farms—1919	
	Average	Range	Average	Range
Winter Wheat	\$1.63	\$.90 to \$4.00	\$1.40	\$.70 to \$3.30
Spring Wheat	1.83	1.10 to 4.00	1.54	.80 to 3.00
All Wheat	1.69	.90 to 4.00	1.44	.70 to 3.30

Crop	Owner Farms—1920		Tenant Farms—1920	
	Average	Range	Average	Range
Winter Wheat	\$1.44	\$.90 to \$3.90	\$1.20	\$.80 to \$3.00
Spring Wheat	1.70	1.00 to 3.90	1.62	1.10 to 4.10
All Wheat	1.56	.90 to 3.40	1.40	.80 to 3.50

It will be seen that the tenants produced wheat at a lower cost than did the owners. This difference is due principally to the fact that the cost of production was charged with 6% interest on the value of the owner's capital in the case of farms operated by owners, whereas, the cost of production on tenant farms was charged with the portion of the crop delivered for rent which amounted to considerably less than 6% on the landlord's investment.

The following table shows a comparison between the cost of producing wheat after fallow, after peas and after other crops.

	Winter Wheat after:					
	Fallow		Peas		Other Crops	
	1919	1920	1919	1920	1919	1920
Number of farms	69	71	10	7	15	15
Yield per acre (bu)	32.0	36.6	33.6	38.1	21.0	21.8
Total cost per bushel....	\$1.75	\$1.50	\$1.18	\$1.09	\$1.65	\$1.69
Operating exp. per bu.	1.14	.94	.85	.81	1.19	1.28

BASIC ACRE REQUIREMENTS

Direct man labor, hrs.	8.0	7.8	6.4	5.8	6.0	6.5
Horse labor, hours	33.7	33.1	22.4	17.8	22.9	26.0
Seed, bushels	1.4	1.5	1.4	1.5	1.3	1.4
Twine, pounds	2.9	3.0	3.5	3.2	2.1	2.1
Per cent all direct labor is						
of operating expense	32.8	27.8	29.8	23.9	37.1	31.5
Total Cost	21.3	17.4	21.4	13.4	26.8	23.9

The operating expenses per bushel plus interest on the capital invested will equal the total cost per bushel.

This Division co-operated with the Office of Farm Management of the U. S. Department of Agriculture in securing farm management survey records from over 250 logged off upland farms in western Washington during August, September and October, 1921. The data are being prepared for publication by the Office of Farm Management.

A two-year study of the cost of milk production in Spokane and Stevens Counties was begun in April, 1922. This work is being done in co-operation with the Chambers of Commerce of Cheney and Spokane, who contributed \$300 toward the cost of the investigation. This survey is designed to supplement the study on the cost of milk production in western Washington.

This Division also co-operated with the Bureau of Plant Industry in beginning a study of the relative profits from the leading crops grown in general farming under irrigation in the Yakima Valley. If funds permit it is expected to continue this survey for three years or more.

Needs of the Division:

The cost of production and farm organization studies should be continued until reliable data have been secured on all the most important types of farming in Washington. This involves the employment of at least one full time investigator on the staff of the division together with at least one full time clerk.

DIVISION OF HORTICULTURE

O. M. Morris in Charge.

The investigational work in Horticulture was confined to four main projects, namely, Apple Rosette, Orchard Cover Crops, Fruit Storage and Seed Potato Production. The field work was done largely in the orchards and on the farms of practical growers in the irrigated valleys and west of the Cascades.

Apple Rosette:

Apple Rosette seems to be peculiar to the northwest. It has not been found east of the irrigated belt on the east slope of the

Rocky Mountains or west of the Cascades. It is found only in alkali soil districts and in practically every case has disappeared within three years after an orchard is planted to a leguminous cover crop. The trouble apparently is physiological and not due to any fungus organism. The appearance of the disease is marked by a chlorosis of the foliage and long narrow leaves much smaller than normal size. The twigs produce a large number of leaves in proportion to their length and form distinct rosettes at the terminal. The disease is cumulative and the twigs that are excessively shortened in one summer's growth usually die the following year. Exceptions are found, however, in which the twig renews normal vigor and assumes normal character of growth. When affected twigs have been grafted as scions onto normal wood, a large per cent have died. Those which have lived have assumed normal growth and vigor. All efforts to reproduce the disease by inoculation have failed as have all efforts to produce the disease in pot grown trees.

Chemical analysis of the affected and normal materials show that the rosetted twigs and foliage have a much higher ash and nitrogen content than the normal twigs. The practice of growing leguminous cover crops in orchards generally seems to be a satisfactory remedy.

Orchard Cover Crops:

Fertilizer plots in the orchards in Spokane Valley received nitrogen phosphorus and potash separately and in combination. None of the commercial fertilizers used were of any particular value to these orchards except when used in orchards the growth of which showed a distinctly sub-normal character and in which a cover crop was being established. In plots in which the cover crop had been established for some years no effects of the fertilizer could be discovered. As reported last year, the combination of leguminous cover crops and nitrogen-bearing fertilizers gave indications of improvement in tree growth and fruit production.

Hayry or winter vetch, field peas, red clover and alfalfa are being used successfully as cover crops in the valley. Very gratifying results have been obtained with the use of vetch, field peas and clover. Alfalfa gives indications of producing splendid results, but it is evident that a much longer time will be required to secure good results with this plant than with the other crops mentioned. The best results with vetch and field peas are secured by planting these crops very early in the spring and letting them grow thru the entire summer.

In the Wenatchee District, the work has been conducted in co-operation with Chelan County. A preliminary report was made in Popular Bulletin No. 121, published in September, 1921. The following facts were established:

1. Nitrogen-bearing fertilizers are the only commercial fertilizers that have produced improvement in the apple tree growth and in fruit production.

2. Barn yard manure when used as fertilizer produces good tree growth and fruit and improves the physical condition of the soil.

3. A legume cover crop improves the fertility and physical condition of the soil.

4. There is little or no disking and no cutting of hay required in the proper handling of the cover crop in the irrigated valleys.

5. Irrigation should be thorough and regular.

In this section, nitrogen-bearing fertilizers are the only commercial fertilizers that have constantly given improvement in tree growth or crop production. The physical condition of the heavy soils seems to be a more important matter for consideration than a modification of the chemical content of the soil. The use of cover crops results in a distinct improvement in the soil of these orchards and in many cases a corresponding decrease in high color of the red fruited varieties of apples.

A series of experimental fertilizer and cover crop plots have been established in five different orchards in Yakima Valley. In these a study was made late in the summer of 1921 of the effects of commercial fertilizers in the orchards. Improvement in tree growth and development was evident in every case where nitrogen-bearing fertilizers had been used. No orchards were found in which the non-nitrogen bearing fertilizers produced any noticeable improvement in tree growth.

A six acre apple orchard was planted on the Branch Irrigation Station farm at Prosser. Here the relative value of different systems of soil management in orchard development is being tested.

Fruit Storage:

Varieties like the Jonathan, Stayman, Delicious, King David and Wagener, mature before they are well colored. In a season like the fall of 1922, when weather continues warm until late in autumn, these varieties will often ripen on the trees before attaining the desired color. The investigational work on fruit storage of the last two seasons indicate clearly that such factors as color of fruit, color of seeds, size of fruit or ease with which it breaks from the stem, or a combination of these cannot be used as a safe guide in determining when these varieties should be picked.

Seed Potato Production:

Work on seed potato production has now been continued through three seasons. The results secured indicate that there are three common factors involved in the production of good seed potatoes. These are, locality in which grown, freedom from disease and cultural care, and selection of stock and storage of seed material.

A number of varieties were eliminated and only the Netted Gem and Burbank continued. Sixteen strains of Netted Gems and eight strains of Burbanks were planted in ten acre plots and their yields compared for the season.

This year's work was started for the purpose of determining the relative importance of various factors in the production of the good seed potatoes. The material will be grown each year at the Experiment Station at Pullman and the Branch Irrigation Station at Prosser and seed material exchanged. Material is planted at different dates at each station. Different methods of storage will be used and an effort made to determine the values of different environmental factors in the production of good seed potatoes.

Needs of the Division:

Because of the large acreage devoted to fruit and the heavy investment in fruit production, it is extremely important that opportunity in time and funds be given for investigating the many problems that confront the fruit grower today and are likely to be encountered in the future.

The heavy loss sustained each year as a result of winter injury to the root system of trees is cause for alarm. Exhaustive investigation should be made of the possibilities of obtaining a more hardy stock and of developing methods of orchard management that will reduce such loss to a minimum.

Investigations should be made to determine the methods of pruning and orchard management that will contribute most to regularity of crop production and improvement in grade and size of fruit. The small apple is a serious handicap to the fruit growers and it does not seem probable that the regularity of crop production and the size of the fruit can be controlled entirely by systems of pruning and soil management commonly practiced.

Investigational work to assist the peach growers in carrying their trees through the winter and late spring in such condition as to avoid as far as possible the danger of late spring frosts should be continued.

Grape growing is a developing industry in the State. Studies of varieties, methods of propagation, tillage methods and systems of pruning and training, are all of importance and should be given attention by the Experiment Station.

Interest in nut growing is increasing. The adaptability of varieties, the degree to which they are self-sterile or self-fertile, the adaptability of the district and systems of orchard management should be determined. This, however, is an expensive operation for the individual and should be done by the Experiment Station.

Vegetable seed production in the United States has become a matter of very considerable importance since the World War. The

climate and soil of Washington have given promise of conditions favorable to the development of that industry. Careful investigation of methods and practices involved are needed.

Methods of management of cranberry bogs is of vital importance to those engaged in this industry. The cranberries in the northwest are produced under methods entirely different from those in the older cranberry sections. Just what methods should be followed is still an open question to be decided only through careful investigations.

There should be at least one additional member of the staff who could devote all his time to the investigational and experimental work. As this work must be done largely in the orchards of practical growers, this man must have a sufficient expense fund and be free to visit different sections of the State at any time when the experimental work makes this desirable or necessary. In addition, there should be at least one pathologist and one entomologist co-operating with the horticulturist and devoting all of their time to investigations of insect pests and diseases affecting fruits.

DIVISION OF PLANT PATHOLOGY

F. D. Heald in Charge.

Wheat Smut:

The following experiments have been completed:

1. A study of the effect of certain seed and soil treatments or cultural practices in ordinary summer fallow.
2. Effect of seed and soil treatments in artificially smutted summer fallow.
3. The relation of copper carbonate dust treatment to germination of wheat.
4. The effectiveness of the Corona compound of copper carbonate.
5. The effectiveness of pure copper carbonate and the determination of the minimum dose.
6. The possibilities of anhydrous copper sulphate as a substitute for copper carbonate dust.
7. The effectiveness of hypoform.
8. The effectiveness of seed-o-san.

The majority of these experiments have formed the basis of Experiment Station Bulletin 171 recently published and consequently only a brief summary will be presented.

1. The treatment of wheat with 2 oz. of copper carbonate per bushel causes no reduction in germination, but rather an improved germination over untreated grain. This has held true for treated seed through a period of eight months following treatment. Copper carbonate-treated seed shows a more rapid germination, a more vigorous growth, and a greater freedom from winter injury than untreated seed. It has given a stand when bluestone and formaldehyde treatments have failed.

2. Copper carbonate dust has proved very efficient in the prevention of smut from seed-borne spores. One-half ounce of copper carbonate per bushel gave nearly as good protection as two ounces, but 3 oz. gave slightly better results than 2 oz.

The maximum per cent of smutted heads in any of the treated samples was 5.41 with a maximum of 64.4 per cent in untreated samples.

3. The efficiency of copper carbonate seems to be due in part to physical properties of the dust rather than solely to the copper content, since 2 oz. of Corona compound containing 17-18 per cent of copper has given as good protection in spring seedlings as 2 oz. of dust containing 50 per cent metallic copper. Hydrated lime as a diluent has not given satisfactory results.

4. Anhydrous copper sulphate plus equal quantities of powdered calcium carbonate or hydrated lime gave the following results as compared with copper carbonate:

Copper Carbonate	Anhydrous) Bluestone) + (Calcium (Carbonate	Anhydrous Bluestone + Hydrated Lime
1 oz. ....0.087 per cent	1.19 per cent	3.03
2 oz. ....0.29 per cent	0.28 per cent	0.70
3 oz. ....0.00 per cent	.....	.....
4 oz.	0.79 per cent	0.56

The treatments with the anhydrous bluestone were only slightly less effective than with the pure copper carbonate. With 2 oz. or more per bushel, hydrated lime was about as satisfactory as the powdered calcium carbonate for mixing with the anhydrous bluestone. It seems possible that with careful attention to the physical properties of the dusts used, anhydrous bluestone may prove to be an efficient substitute for the more expensive copper carbonate.

5. Copper carbonate has given better protection against smut from soil contamination than formaldehyde, and is equal to or better than bluestone treatments. Convincing quantitative data on increase of yields by use of copper carbonate are lacking, but farm reports claim an increase.

6. Hypoform at a strength of 1 pound to 5 gallons of water which gave a smut-free crop last season, afforded but little protection this year in spring plantings. Seed-o-san, an organic mercury compound used as a dust (2 oz. per bushel), gave nearly as good protection as an equal quantity of copper carbonate.

Foot Rot of Wheat:

Investigations of this disease were conducted in co-operation with the Office of Cereal Investigations of the U. S. Department of Agriculture.

Field experiments were carried out on the Arthur D. Jones ranch in the Spokane Valley to determine the relation between date of seeding and foot-rot; the comparative resistance of varieties, the effect of various fertilizers on the amount of foot-rot; the source of the infestation; and the relation of the physical condition of the soil to the severity of the disease. The variety tests were in co-operation with the Farm Crops Division of the College and the fertilizer tests in co-operation with the Department of Soils.

The season was one marked by very slight rainfall and high temperatures and the foot-rot which had been so severe in the previous season failed to develop. It was to be found in only slight traces in any fields, consequently, the experiments yielded no data on foot-rot.

In the periodic seedings the highest yield of Forty Fold was obtained from the planting of September 12. Many of the varieties tested were killed by the severe winter conditions. Of the varieties which did over winter the three highest yielders were Hybrid 128, Kanred and Kharkov, ranking in the order named. No conclusions could be drawn from the fertilizer tests.

Laboratory and greenhouse studies were made of the fungus which had been repeatedly isolated from wheat plants affected with foot-rot. In all cultures the fungus remained sterile, and no fruiting stage was found upon the old stubble brought from infested fields. Wheat was grown at Pullman in soil brought from the Spokane Valley and inoculations made with pure cultures of the organism failed to reproduce the disease. The identity and pathogenicity of the associated organism therefore remains in doubt.

Oat Smut:

Tests were made of the value of copper carbonate dust in the prevention of kernel or covered smut (*Ustilago levis*). The varieties were selected: Chinese Hullers, very susceptible; Swedish Select, moderately susceptible; and Abundance, more resistant. Each variety was artificially smutted, using three different degrees of smutting, light, medium and heavy. Two, three and four ounces of copper carbonate dust per bushel were tested with the following results:

VARIETY	Check of untreated Seed	Average per cent Smutted heads for 3 degrees of smutting		
		2 oz.	3 oz.	4 oz.
Chinese Hullers	70.45	0	0	1.0
Swedish Select	28.18	2.9	2.8	2.3
Abundance	18.79	6.14	3.55	3.6

The results show that the copper carbonate is not so effective as similar treatments for bunt, but they justify further experiments.

Cranberry Investigations:

In co-operation with the Extension Service of the College and with Pacific County, a laboratory was established at Ilwaco for the study of cranberry problems, with special emphasis on fungous diseases. It was necessary, however, to give attention to all phases of cranberry culture. Field experiments were started for the control of both insect pests and fungous diseases, and a laboratory study is being made of the fungi causing loss in storage. Mr. D. J. Crowley was located at the Cranberry laboratory during the summer and is continuing the work on the storage rots. The results of the work will not be available for several months but enough has been done to show that the fungous diseases are much more serious than was anticipated. Two of the most serious rots have developed in abundance in the storage work, even though the season was excessively dry, with practically no rain until after the berries were picked. The work has also shown that the fire-worm, the most serious insect pest, is not being controlled by the nicotine spray that had been recommended, and that very slight injury to berries by this pest is responsible for much of the rot in storage by offering an easier avenue of entrance for the rot-producing fungi. The seriousness of the problems which face the cranberry growers demands continuation of these investigations.

Rhizoctonia Diseases:

The Rhizoctonia disease of potatoes was studied along three lines: Seed treatment, cultural practices as control measures, and studies to determine the importance of this disease in the crop.

Infected seed was treated with copper carbonate at the rate of four and ten grams per bushel, the amounts that would adhere to dry and wet or freshly cut tubers respectively. 4.6 per cent of clean tubers were produced in the check plot and 23.4, 6.8 and 2.5 per cent in the three treated plots showing that the results were rather erratic. It is felt, however, that this test is worth repeating.

Periodic plantings of clean and infected, treated and untreated seed stock were made at intervals of two weeks from the time the ground could be first worked until the first of July. This test was

duplicated at the Irrigation Branch Station at Prosser with the same seed stock. Mid-season plantings (May 20) gave the largest total yield and also the largest yield of table stock. The last planting (July 1) gave the largest percentage of clean tubers. Plantings after the first of June showed a steady increase in percentage of clean tubers over the plantings before that time which showed little variation and a low percentage of clean tubers in treated or untreated stock. In the later plantings, seed treatment with corrosive sublimate increased the per cent of clean tubers over untreated clean or infected seed. Results of the test at the Irrigation Branch Experiment Station are not yet available.

To determine the relation of *Rhizoctonia* to leaf roll, mottling, streaking and curling of foliage, cuttings were taken from potato plants and an attempt made to root them in sand. None of the cuttings from badly affected plants rooted. A small percentage of cuttings from less severely diseased plants rooted and are being grown to determine the symptoms that will carry over into the resulting plants. To study this problem from another angle, hill selections were made of plants showing symptoms of disease, some of which were suspected of being induced by *Rhizoctonia*. It is planned to grow this stock in the greenhouse and to study the diseases present.

The study of the western yellow blight of tomato was continued. Previous work has failed to prove conclusively that this disease is due either to *Rhizoctonia* or *Fusarium* species. A test was made by inoculating tomato plants with cultures isolated from diseased tomato roots of each of these fungi and both together without being successful in producing a larger percentage of disease in inoculated than in check plants. The behavior of diseased plants and outcome of previous experimental work has suggested that this disease is one of the virus troubles. To test this, cuttings were taken from diseased plants and an attempt made to root them in sand and a mixture of soil and sand. A very few of these cuttings have taken root and developed about as cuttings from normal plants. Out of thirty-five dozen cuttings taken from fifteen diseased plants only two dozen and a half lived two months. The failure of these cuttings to recover from the diseased condition apparent on the plant tends to strengthen the theory that this is a virus trouble.

Study has been continued on the fungus flora on the root system of diseased plants. For comparative purposes an examination was made of plants showing none of the disease at any time during the growing season. Thirty-three were examined out of a plot of forty-six plants. One hundred per cent of these showed the mycelium of *Rhizoctonia* in abundance and fifty-seven per cent showed pronounced sclerotial development on the roots. This shows that the

tomato may be infected with this fungus and not show the symptoms of the blight.

The Plant Disease Survey:

This work has been continued as in former years with the co-operation of the Plant Disease Survey Office of the U. S. Department of Agriculture. As compared with previous seasons, the past season has been conspicuously free from epiphytotic, presumably on account of the excessive drought. Such troubles as foot-rot of wheat and Sclerotinia wilt of sunflowers, which were severe in 1921, were not reported this year. The rusts of cereals were either entirely absent or very inconspicuous. Smut of wheat (*Tilletia tritici*) however caused a heavier loss than in 1921.

The aecial stage of "*Puccinia coronifera*" on buckthorn, "*Rhamnus purshiana*" was abundant in western Washington. It is worthy of note that a single collection was made of the aecial stage of stem rust ("*Puccinia graminis*") on barberry at Mt. Vernon. The Fusarium rot of onions was again prevalent in the Walla Walla section and there were heavy losses in shipments to eastern markets as a result of slimy soft rot. There were numerous reports of Rhizoctonia injury to strawberries during the early part of the season. The same fungus was also responsible for considerable rot in ripening tomatoes and the fruiting stage was common on fruits in contact with the moist soil during September. Rust of snapdragon was reported from a new locality and the data reported indicated that it was introduced with the seed.

The aecial stage of "*Puccinia sarcobati*" was common on spinach in the Walla Walla truck section and was responsible for considerable loss to the growers, owing to the rejection of shipments. This rejection was due to the disfiguring of the leaves by the groups of cluster cups, rather than to any real injury. The rust in question was found producing its over-wintering stage in great abundance on salt grass ("*Distichlis spicata*") which is common along the roadsides and in pastures. Spinach rust was first reported from Yakima Valley in 1919, but this was its first appearance in the Walla Walla section. Spinach rust is known to produce its aecial stage on numerous hosts in other sections, but search of the Walla Walla district failed to reveal it on any other host.

Dr. C. K. Link of the U. S. Department of Agriculture and Mr. Currey, Seed Inspector of the State Department of Agriculture, report the general and wide-spread occurrence of potato mosaic in the State. Despite this menace to the potato industry, there has been a marked increase in production over previous years. The relation of mosaic to the seed industry and a more detailed study of the disease under diverse conditions is a problem that demands investigation.

A few diseases new to the State have been recorded: (1) A storage rot of apple due to an undescribed species of *Dothichiza*; (2) The downy mildew (*Peronospora riciae*) of garden pea; (3) A dry rot of rhizomes of ginseng caused by a *Ramularia*.

Some Needs of the Division of Plant Pathology:

The needs of the Division remain essentially the same as outlined in the last annual report, but some need additional emphasis. Work on cranberry diseases in Pacific County was commenced. The pathologist spent six weeks in the field on this work. If these cranberry investigations are to be continued, there must be a very material increase in financial support.

The disease problems which are calling for investigation in addition to those listed in the last annual report are as follows:

1. The rust of spinach and the relation of the casual fungus to salt grass and other hosts.
2. Gum pockets or drought spot of prunes.
3. The mosaic disease of the potato.
4. The relation of the *Fusarium* rot of onions to the slimy soft rot which develops during transportation to market.

DIVISION OF SOILS

F. J. Slevers in Charge.

Soil Nitrate Studies:

Work was continued to determine and control the factors that influence the effect of straw applications on the productivity of Palouse soils. Past results have shown that when straw is plowed under just before seeding, the available nitrogen is withdrawn from the soil, that yields are reduced and that an inferior quality of product is obtained. The past season an experiment was planned to determine if straw would show the same effect after summer fallow tillage, with the result that the general depressing effect, altho not very pronounced was sufficiently in evidence to be of economic significance. Much of this, however, should be attributed to the extremely dry season of 1921 and 1922, which made it difficult to obtain conditions favorable for organic decomposition in the soil. Consistent with this contention, the greatest reduction in nitrates and yield was obtained where the moisture content in the surface soil was lowest, with practically no reduction where the surface soil moisture was maintained at a percentage optimum for nitrification. This emphasizes the value of effective summer fallow. Further indications from field and laboratory experiments are that the effect of straw is not as easily overcome when it is applied to the poorer soils. Since summer fallowing is primarily practiced to promote the decomposition

of soil organic matter, the difficulty experienced in returning straw will become more pronounced from year to year as soil organic matter becomes more depleted.

Supplementary results were obtained this season on the development of the wheat plant as influenced by soil nitrate content and rate of seeding. Hybrid 128 wheat was sown on soils with a low, a medium and a high nitrate content at rates of 30, 60, 120 and 240 pounds per acre.

The results showed that the number of heads per given area increased slightly with the rate of seeding, but not in proportion to the amount of seed sown. The size of both the heads and straw decreased as the seeding rate increased. Tillering was most pronounced under the 30 pound seeding rate. Where 240 pounds of seed were sown, only about 50 per cent of the plants produced heads. The extreme variations in the rate of seeding had very little effect on yield during this season. Soil nitrates, however, showed the same effect on yield as was reported previously, namely, that the yields of wheat vary almost in direct proportion to the nitrate content under field conditions in the Palouse region of Eastern Washington.

Soil Fertility Problems in Western Washington:

Work was continued on Western Washington soils and the results from investigations confirm and supplement former conclusions concerning the fertility and management of various soils types.

The muck and peat soils are all deficient in both potassium and phosphorus, but this deficiency from the standpoint of availability is most pronounced on those soils where the organic matter is least decomposed. Practically all of these soils show a direct benefit from an application of a potash fertilizer used singly, while phosphate fertilizers will increase crop yields only when used in connection with a potash fertilizer.

Sands and sandy loams, especially those of the poorer type found on the higher elevations are, as a rule, very deficient in nitrogen, phosphorus, potassium and lime, and those that were originally timbered may be so limited in available plant food even in their virgin state that it may be impossible to obtain a successful crop even the first year after clearing. These soils need to be built up at the beginning with clover, vetch, or any other legumes that are well adapted. Most legumes will not grow well here unless the soils are first treated with at least one ton of lime per acre supplemented with about 300 pounds of phosphorus potassium fertilizer.

Tide lands vary very decidedly in their productivity. Those that had developed luxuriant vegetation before they were reclaimed are well supplied with available plant food and will produce abundantly without special treatment. Where such vegetation had not developed, the soils are in poor physical condition and also quite limited in

organic matter and nitrogen. Since some of these soils did not support vegetation evidently because of the presence of excessive amounts of alkali salts, they need to be leached for a few years before crops can be grown with any degree of success. Under all conditions it will be difficult to get any vegetation to grow on these soils without the use of a nitrogen fertilizer. The first few crops grown should be used as green manure to improve the physical condition, so that eventually the nitrogen supply may be taken care of by developing a condition suitable for growing legumes in crop rotations.

The silt and clay loams and the alluvial soils along the streams are generally deficient in phosphorus and lime. Soil acidity and a lack of phosphorus are closely related on all these soils. Animal manure, which is frequently available in large quantities will produce excellent returns here. If manure is not available, applications of both phosphorus and lime are necessary for best results, especially where it is the intention to introduce a rotation system including a legume that is sensitive to soil acidity. On farms where the supply of manure is limited, larger acreage may be treated at more frequent intervals if a phosphorus fertilizer is used as a supplement.

Arid Soil Investigations:

Chemical determinations for calcium, calcium carbonate, phosphorus, potassium, nitrogen and carbon were made of a large number of soil samples selected in Eastern Washington in an attempt to determine the effect of variations in precipitation on soil composition. The annual precipitation varies in this region from 7.5 inches in the Columbia River Valley to 21.5 inches near the Idaho boundary. It was found that these variations in precipitation had practically no effect on the amount of calcium, calcium carbonate, potassium and phosphorus present, and that very little calcium existed in the carbonate form in the surface soil, irrespective of precipitation. There was a direct variation in the amount of nitrogen and carbon in that these elements increased with the precipitation. In spite of this increase, the ratio of nitrogen to carbon remained practically constant at 1 : 12 for all samples. The fact that this ratio is practically the same as that found for soils in the humid section of the world indicates that the general belief that the organic matter in arid soils has a higher nitrogen content than that found in soils from the regions of heavier precipitation has little scientific foundation.

Mechanical analyses of the same soil samples showed a direct relationship between soil texture and precipitation. Soils from the regions of greater precipitation, without exception, showed higher percentages of silt but practically no variation in the percentages of the other separates.

Magnesium Carbonate Injury:

The effect of magnesium oxide dust on the soil, when deposited in excessive quantities was studied from the standpoint of its influence on plant development. This dust had been emitted by a magnesite roaster and distributed thru the air to become deposited in the form of a heavy crust on the surrounding agricultural land. It was found that this magnesium oxide was changed to the carbonate form soon after its deposition; that where present in large amounts it produced an alkali condition in the soil; that the deposit developed a crust of such physical consistency as to prevent young plants from penetrating it, and that enough of the magnesium salt went into solution to produce a toxic effect sufficiently pronounced to prevent the development of common agricultural plants on soils where the crust was much in evidence. Its destructive effect was felt over an area described by a radius of about one and one-half miles, and was most pronounced in closest proximity to the roaster and on those soils lowest in volume weight, it being especially evident on muck and peat soils.

Pot experiments with virgin soils from the region injured by the magnesite dust showed that light applications of magnesium carbonate might prove beneficial to plant development even tho the soils were normally very productive.

Soils Under Irrigation:

All irrigated soils in the arid portion of Washington are decidedly deficient in nitrogen. This deficiency may be readily overcome in general farm practice thru the introduction of a legume crop into the rotation system. All of the common legumes are exceptionally well adapted to both soil and climate but choice is generally limited to alfalfa, red clover and sweet clover because of their better suitability to the general system of farm management as practiced.

The total amount of phosphorus in arid soil is comparatively limited but shows a high percentage of availability. After several years of heavy crop production under irrigated conditions, the available phosphorus soon becomes depleted to the extent that phosphorus fertilizers may be used to advantage on some of the older irrigated fields.

Continuous clean cultivation of orchards exhausts the organic matter and develops a hard, compact subsoil immediately below the depth of the plowed layer as well as a very poor physical condition of the surface soil. The compact subsoil is the result of the cumulative effect from the pressure of the plow together with the weight of the furrow horse in plowing on the bottom of the furrow. This compact condition interferes with the penetration of moisture and the efficient use of irrigation water. This so-called hard pan does not develop in fields

where crops are grown and the benefits derived from growing a legume like alfalfa in an orchard, evidenced by better fruit and wood growth, can in large part be attributed to the breaking up of this subsoil. The growing of legumes also benefits the physical condition of the surface from the standpoint of water penetration.

Sulfur used on the soil as gypsum or as elemental sulfur has shown marked increases in the yield of alfalfa in the upper portion of the Yakima Valley. It has not been determined whether sulfur functions here directly as a plant food or indirectly as a stimulant by making other plant food elements more available to the crop.

Soil Surveys:

To aid in the land settlement program, this division co-operated with the State Department of Conservation and Development by making soil surveys and reports covering the following areas:

- 12,013.5 acres near Pasco in Franklin County
- 1,020 acres near Soap Lake in Grant County
- 1,200 acres near Shelton in Mason County

Miscellaneous Work:

Seven hundred sixty samples of soil sent in by farmers were tested and reported on for fertility. In all cases recommendations were made concerning the management of these soils not only to maintain the fertility but to increase their productivity.

Eighty-six samples of soil were tested for alkali and recommendations made concerning the management of alkali tracts.

Twelve samples of limestone and marl were tested for their suitability for neutralizing acid soil.

Needs:

Because of the extreme variations in climatic and soil conditions, the demands for service from this division are numerous. Due to limited financial support, it has been possible to give attention only to those problems that could be handled with least expense and that appeared most pressing. This State is at present deeply interested in a very extensive development and reclamation program. Before any large land development program pertaining to the utilization of cut-over land or the reclamation by irrigation of such extensive areas as the Columbia Basin Project can be entered into sanely, its agricultural possibilities should be thoroly and definitely understood. A soil survey furnishes such information in a scientific and unbiased manner and provision for such work should be made at this time. The cost of such surveys is so meager as compared to its value in eliminating the financial sacrifices and human sufferings that are generally endured where the settler himself must gain all his information by experience, that economy demands that such surveys precede any development or reclamation work.

DIVISION OF VETERINARY SCIENCE

J. W. Kalkus in Charge.

Orchard Horse Diseases:

During the year, the investigation of this disease has been confined almost entirely to work with small laboratory animals.

Chemical analysis of samples of orchard hay, which was fatal to horses when fed both under ranch conditions and experimentally at the station at Pullman, shows the presence of approximately .66 grams of lead arsenate to each twenty pounds of hay.

When fed experimentally to guinea pigs, this hay proved fatal in from three to five weeks. A healthy pig weighing about 300 grams usually succumbs after consuming about five pounds of the hay.

Wholesome hay poisoned with definite quantities of lead arsenate, .66 grams, 1.5 grams, and 5 grams, respectively, to each 20 pounds of hay did not prove fatal when fed to guinea pigs as an exclusive diet for a period of 20 weeks, during which time each pig consumed about 14 pounds of the poisoned hay. These experiments seem to indicate that altho orchard hay containing lead arsenate is capable of causing the death of guinea pigs, this is not directly due to poisoning by the lead arsenate present, since the wholesome hay poisoned with a quantity of the lead arsenate amounting to more than seven times the quantity found in orchard hay did not produce death in guinea pigs, even after such experimental animals had consumed almost three times the quantity of hay that was required to kill with orchard hay.

The addition of a few green leaves to the diet of guinea pigs being fed orchard hay prevents the fatal action which follows the feeding of such hay exclusively. This might indicate that the presence of lead arsenate in hay may be responsible for the destruction of certain substances which maintain a proper nutritional balance in the living animal.

Guinea pigs immunized against bacillus botulinus A. and B. with the use of the respective antitoxins were not protected against the fatal action of orchard hay. This would indicate that botulism was not a factor in the production of orchard horse disease.

In all the feeding experiments with guinea pigs proper, control animals were maintained on wholesome hay. It is impossible at the present time to draw any definite conclusion in regard to orchard horse disease, because the results obtained with guinea pigs are not always obtained with larger animals. The experiments with guinea pigs should be duplicated with horses. In all probability, orchard horse disease is due to lead arsenate spray but whether this is directly or indirectly responsible for the symptoms and lesions produced can only be proven by further investigations.

At the present time, orchard horse disease is of very little importance directly from an economic standpoint, although it was a serious

economic problem when these investigations were commenced. Most orchardists have ceased entirely to use their orchard grown hay as feed for livestock, not only because of the danger of poisoning to horses but also because of the fact of changed orchard practice, which teaches that it is far more economical to use the alfalfa grown in orchards as a means of fertilization. Most orchardists are now of the opinion that it is in reality an economic loss to harvest the orchard grown hay.

Red Water in Cattle:

Altho this disease is still under consideration as a project of the Division of Veterinary Science, no active work has been done with reference to the investigation of this trouble during the past year. Many inquiries are received from owners of cattle in those sections of the State where this trouble is common and these are answered promptly and such advice as is available at the present time with reference to the treatment for the control of this condition is given.

Needs of the Division:

If very much progress is to be made in this division in the investigation of animal diseases in the future, it will be necessary first of all to employ additional help for the work. The time of the veterinarian is so occupied with numerous duties on the campus that it is practically impossible for him to devote a great deal of time to detail work. It is, therefore, suggested that in the very near future an assistant veterinarian be added to the staff. Adequate housing facilities should also be provided to house both large and small experimental animals. Additional funds should be made available for this division in order that animal diseases of economic importance in the State could be given special attention. Among these may be named contagious abortion, sterility and allied diseases of breeding cattle, sheep diseases, poultry diseases, and walking diseases of horses. Attention is also called to the fact that in many instances outbreaks of disease among domestic animals appear suddenly and unless provision is made for investigation at the time of their appearance it is not possible to make the study at the most opportune time. For this reason it would be well to have a small fund set aside for the Veterinary Division for emergency use. Then in the event that an outbreak of disease occurred anywhere in the State it could be investigated at once by the station veterinarian and if deemed of sufficient importance could be given further study.

ADAMS BRANCH EXPERIMENT STATION

M. A. McCall in Charge.

Crop Experiments:

Crop experimentation is continued as in the past, except that this line of investigation has been broadened to include a study of

physiological factors, centered largely on the wheat plant. Preliminary results have shown that photoperiodism (the response of the plant to the relative amount of sunlight during twenty-four hours) controls the various stages of development in the wheat plant, and that differences between winter and spring wheats or between varieties in either group are largely determined by this factor. A continuation of this study and an enlargement to include soil and other factors is being undertaken. All will be considered primarily in their relation to the practical phases of crop production, upon which observation indicates they have an important bearing. In this consideration will be included varietal distribution in relation to soil type, soil fertility, rainfall, temperatures, beginning and end of growing season, and any other elements concerned in either local or regional distribution and performance. Drouth resistance will be one phase of the subject receiving special consideration.

Turkey Red (Washington 326) has proven to be the winter wheat variety most suited to the dry districts of this State. This particular strain of Turkey Red, in addition, is very resistant to stinking smut, as proven by experiments at the central station at Pullman. Experiments at the Adams Station covering a five year period have also shown that in seeding this variety in the drier localities seed treatment is not necessary in preventing smut infection. Seed injury from treatment for smut is a very important cause of failure to secure stands during unfavorable seasons in dry districts and a more wide use of this variety should do much to increase production. At least 2000 acres were sown to Turkey Red (Washington 326) in Adams County in the fall of 1922, this being the increase from seed distributed by this station.

Soil Problems:

Soil problems in connection with summer fallow tillage naturally occupy a prominent place in the program of the station.

Available moisture and plant food, chiefly nitrate-nitrogen, are the two soil factors which most largely determine crops yields in dry farming. Each is capable of control in greater or less degree thru summer fallow tillage operations.

Maximum returns are dependent on the proper balance of controlling factors (in this case moisture and nitrate-nitrogen) and this balance is not necessarily the same for all conditions. Data secured in summer fallow experiments during 1918-1921 indicate that under drouthy conditions, an abundant supply of nitrate-nitrogen, with a consequent heavy yield of straw, tends to reduce yield of grain. During a season of drouth it is more important, therefore, to center tillage operations on saving a maximum supply of soil moisture, rather than on developing nitrates.

These tillage experiments also show conclusively that the earliest

possible spring preparation of the summer fallow leads to a greater accumulation of nitrates than does preparation at a medium spring date; but that very early preparation does not conserve appreciably more moisture than that at the medium date, provided the latter be before volunteer grain and weeds begin active growth. In a drouthy season, when the soil in early spring has absorbed but a limited supply of moisture, the preparation of fallow should, therefore, be so timed that most of it will be done at as nearly a medium spring date as possible. In more moist seasons, with large supplies of soil moisture, preparation should be at the earliest possible date, and subsequent treatment such as to develop an abundant supply of nitrate-nitrogen.

The four correlation tables given below are the basis for the above conclusions. Tables 1 and 2 are made from data secured from 148 individual plats and tables 3 and 4 are made from data secured from 131 plats.

A correlation table is a visual presentation of the relation which exists between two factors, in the case of table 1, between the soil moisture content at the beginning of the growing season and the resulting yield of grain. The left hand column of table 1 indicates the moisture content of the different plats in tons per acre to a depth of four feet, arranged in a regular increasing scale from top to bottom. At the top of the table is likewise given a similar scale for yield of grain. In the data considered in making up table 1, there were three plats with a moisture content of 351-400 tons per acre and with a yield of from 3-4 bushels of grain. There was one plat with a moisture content of 401-450 tons per acre and a yield of 3-4 bushels, one with the same moisture content with a yield of 5-6 bushels, and so on. If the correlation were perfect and yield were decided solely by soil moisture, with each increase in moisture content there should likewise be an increase in yield, and all instances should fall into a diagonal line extending directly across the table from the right upper corner to the lower left. In this case the correlation is not perfect and all cases do not fall exactly into such a position, yet it is seen that there exists a strong tendency for each instance to not vary widely from such a position. This indicates a decided correlation between yield of grain and soil moisture content, and leads to the conclusion that soil moisture is the most important factor in determining yield of grain.

The coefficient of correlation (r) is a numerical statement of correlation worked out by a mathematical formula which it is unnecessary to discuss here. A perfect correlation is indicated by a value for (r) of 1.0000, while any value of r less than 1.0000 indicates the correlation is not perfect, or in other words, that other factors also have a part in determining the results. A value of r greater than

0.5000 is considered, however, to indicate a decided correlation between two factors under consideration. A value greatly less than this latter figure indicates little relation between the two, the one as cause and the other as effect.

Table 1: Correlation of Soil Moisture and Yield of Grain during the years 1918-1921.

Moisture in Tons per Acre:	Yield of Grain in Bushels per Acre							F
	3-4	5-6	7-8	9-10	11-12	13-14	15-16	
351-400	3							3
401-450	1	1						2
451-500	2	6						8
501-550		19	7	3	1			30
551-600		9	14	13	2	1		39
601-650		1	6	8	16	4	1	36
651-700				1	11	9	4	25
701-750					2		1	3
751-800					1	1		2
F	6	36	27	25	33	15	6	148

$$r = .7805 \pm .0216$$

Table 2: Correlation of Soil Moisture and Yield of Straw during the years 1918-1921.

Moisture in Tons per Acre	Yield of Straw in Pounds per Acre							F
	151-300	301-450	451-600	601-750	751-900	901-1050		
351-400	3							3
401-450	1							1
451-500	3	6						9
501-550	8	17	5					30
551-600	4	23	11	2				40
601-650		9	10	11	5			35
651-700			5	13	6	1		25
701-750			1	1		1		3
751-800				2				2
F	19	55	32	29	11	2		148

$$r = 0.7214 \pm 0.0266$$

Table 3: Correlation of Soil Nitrate-Nitrogen and Yield of Grain during the years 1918-1921.

Nitrate- Nitrogen in Lbs. per Acre	Yield of Grain in Bushels per Acre							F
	3-4	5-6	7-8	9-10	11-12	13-14	15-16	
16-25	1							1
26-35	3	9		4	3	1		20
36-45	2	10	1	3	5	3		24
46-55		13	3	4	10	4	1	35
56-65		3	5	1	7	2		18
66-75		1	13	4	4	2	1	25
76-85			4	3				7
86-95			1					1
F	6	36	27	19	29	12	2	131

$$r = 0.3847 \pm .0502$$

Table 4: Correlation of Soil Nitrate-Nitrogen and Yield of Straw during the year 1918-1921.

Nitrate-Nitrogen in Lbs. per Acre:	Yield of Straw in Pounds per Acre						F
	151- 300	301- 450	451- 600	601- 750	751- 900	901- 1050	
16-25	1						1
26-35	3	10	5	1			19
36-45	5	7	7	5	1		25
46-55	4	13	6	10	2		35
56-65	2	7	5	3	3		20
66-75	3	12	2	2	4		23
76-85		4	3				7
86-95		1					1
F	18	54	28	21	10		131
$r = 0.6395 + .0348$							

The coefficient of correlation (r) of the above four groups of data indicate very clearly the effect on crop return of the two factors considered. The high value of r in the correlation of soil moisture and yield, both of grain and of straw, is evident. Nitrate-nitrogen shows a decided correlation with yield of straw, but not with yield of grain. These facts point to the conclusions given.

Note— r (the coefficient of correlation) is derived by the standard formula as used by Love and Leighty in their biometrical study of cereals.

THE IRRIGATION BRANCH STATION

R. P. Bean in Charge.

Crops Grown in 1922:

Every acre of the 203 acres at the Irrigation Branch Station was in crop in 1922. Alfalfa was grown on 74.7 acres, 72 of which produced 425 tons of hay. The remaining 2.7 acres were used for hog pasture. Of 40.9 acres of corn, 34.9 acres yielded 350 tons of silage and six acres produced seven tons of shelled corn and forty tons of stover. Sweet clover pasture was grown on 23.3 acres and sweet clover hay and seed were harvested on 7.3 acres. A grass and clover mixture for permanent pasture was seeded on 6.7 acres. There were eight acres of wheat, 6.2 acres of peas, 2.3 acres of rye and vetch, and one acre of sunflowers.

The remaining acreage was devoted to experimental work and was apportioned as follows: Apple orchard, six acres; mixed orchard, one acre; border irrigation, six acres; wheat, barley, oats and peas, 5.5 acres; potatoes, four acres; soy beans and cow peas, 1.3 acres, and corn, one acre.

Up to the present time all cultivated crops have of necessity been grown on land which has never produced alfalfa. The seeding program of this year brings all the fields, not used for experimental

work and sweet clover pasture, into alfalfa and permits the starting of a tentative crop rotation for the farm fields. Three fields of three year old alfalfa were fall plowed and will be planted to cultivated crops, chiefly corn and potatoes, in the spring of 1923. These will be harvested in the usual manner and fall grain seeded after they are removed from the fields. Alfalfa will probably follow the grain crops and may be either fall or spring seeded, depending upon the existing conditions. This plan will be generally followed with all the fields until definite results from the Crop Rotation Experiment are obtained, when the rotation system will be handled accordingly.

General Improvement and Equipment Purchased:

The farm was fenced on the east, north and west with a rabbit and stock fence and additional corrals and feed-lots were constructed to handle the livestock. A hollow wall wooden hoop silo 14x44.5 feet was built. A milking shed of knock down type, suitable for summer pasture shade and other necessary dairy equipment have been added. Two more individual farrowing houses and some storage space for seeds from experimental plots have been constructed. A Fordson tractor to be used principally for belt power, a two way plow, a grain thresher for use in connection with the experimental work, a grain cleaner and various pieces of scientific equipment were purchased.

Through the helpful interest of the Board of County Commissioners of Benton County and of the State Highway Department, the County graded and graveled the one and one-half miles of road from the Yellowstone Trail to the Station at a cost of approximately \$8000. The money was appropriated for this purpose from the county's portion of the State Highway Fund.

Experimental Work With Farm Crops:

The work with farm crops consisted of field tests and trials of varieties of alfalfa, wheat, barley, oats, field peas and corn. The time of cutting experiment with alfalfa, started in 1921, was continued.

Alfalfa varieties on one year old stand produced three crops with total tonnage as follows: Kansas Common, 7.6; Dakota Common, 7.2; Canadian variegated, 6.6; Peruvian, 6.6; Baltic, 6.5; Grimm, 6.2; and Turkestan, 4.2 tons per acre. A two year comparison of Dakota Common and Turkestan in the field gives an average yield of 7.1 and 5.3 tons respectively.

The two year average results of "The Time of Cutting Experiment" places the "¾-full bloom" stage first with a yield of 8.1 tons per acre, ½ in bloom second with 7.8 and just before blooming last with 6.7. The analysis of a sample from each stage of bloom each cutting this year, will be made to determine as far as possible the value of the same for feed.

The varieties of winter wheat and barley were grown on land which had been in alfalfa for two years. Those of spring wheat, barley, oats and field peas were grown on land which has never grown alfalfa but had a slight application of manure before plowing. The three leading varieties of each of these crops with their respective yield in bushels per acre are as follows:

Winter Wheat—Hybrid 128, 40.5; Turkey, 38.2;

Winter Barley—White Winter, 54.2; Maryland Winter, 38.9; Chevalier Winter, 32.8.

Spring Wheat—Dicklow, 23.6; Bluestem, 23.2; Early Baart, 21.9.

Spring Barley—Mariout, 26.1; Blue, 22.5; Beldi, 22.2.

Oats—Banner, 45.0; Victory, 43.7; Swedish Select, 43.1.

Field Peas—Kaiser, 30.1; Canada, 27.3; Bluebell and Early Alaska, 25.1.

The varieties of corn under investigation were grown in the west half of the experimental orchard. The land had not grown alfalfa but was given a slight application of manure before plowing. The corn was planted May 22. The late planting gave the earlier maturing varieties the advantage. Windus White Dent led with 35.9 bushels per acre, and Thayer Yellow Dent and local grown Yellow Dent each produced 32.9 bushels. The yield of silage was relatively low, the highest being 8.7 tons per acre for Reid Yellow Dent from Iowa grown seed.

Rhizoctonia of Potatoes:

Periodic plantings of clean and infected treated and untreated seed stock were made at two week intervals from April 1 to July 15 inclusive. Treatment increased the yield from both clean and infected seed. The percentage of clean tubers in the table stock was increased from 80.3 to 93.0 for clean seed and from 19.7 to 80.1 for infected seed. Plantings from May 15 to July 1 had less infection and produced a much greater yield of salable potatoes than the earlier plantings.

Fertilizers and Crop Rotations:

A fertilizer experiment was begun on new land with potatoes as the crop grown this year. Two check plots on which no fertilizer was used produced an average total yield of 5.815 tons per acre. In order to show the relative value of each of the fertilizers, the total yield per acre on each plot is given in percentage of the average total of the check plots. The percentages are as follows: Horse yard manure (14 tons per acre) 130.6%; ammonium sulphate (150 lbs.) 118.8%; sheep manure (15 tons) 116.6%; land plaster (200 lbs.) 102.8%; alfalfa hay, (2 tons) 100.1%; "Soda Nitrogen," (150 lbs.) 96.2%, and sodium nitrate, (150 lbs.) 91.1%.

The area for permanent crop rotation and fertilizer work has been established. It contains 60 one-twentieth acre plots and is now seeded to alfalfa. The experiment will be started in 1925.

Dairy Herd and Pasture Studies:

Seven two-year-old purebred Holstein heifers were purchased from the Dairy Department of the State College at Pullman as a foundation herd for this station. They are by Segis Pontiac Acme and bred to Piebe Hero, the senior and junior bulls of the college herd. A young bull by Sir Thorndyke Ormsby Piebe has been purchased to head the new herd. The cows will be used for pasture experiments and for marketing some of the home grown feed as butterfat. It is planned to develop a one-man sized herd of good producers and to provide a practical barn economically equipped.

Hogs and Hog Feeding:

Five pure bred sows were purchased from the State College herd at Pullman in 1921 and a breeding herd now consists of young sows bred and developed on the station. A young boar of similar breeding was purchased in the spring of 1921 from a Yakima Valley breeder. The fall litters of this mating are of uniform and promising type apparently adapted to experimental feeding and the conversion of grain and pasture into pork.

In the experimental work, thirty pigs farrowed in the fall of 1921 were pastured on alfalfa until December 15. They were then divided into two lots. Lot I was fed corn, fishmeal and millrun. Lot II likewise received corn and fishmeal but alfalfa hay was substituted for the millrun. Lot I gained at the rate of 1.92 pounds per pig daily, Lot II at the rate of 1.76 pounds. At the close of the experiment, April 11, the pigs of Lot I averaged 183.5 pounds and were practically fat enough for market. The pigs in Lot II averaged 172 pounds and were in excellent condition for fattening. Lot I received 315 pounds of corn and fishmeal and 100 pounds of millrun for every 100 pounds of gain. Lot II received 350 pounds of corn and fishmeal and 87 pounds of alfalfa for every 100 pounds of gain.

Thirty-five 1922 spring farrowed pigs were pastured on alfalfa and fed a two per cent ration of corn and fishmeal. These are now being fattened on home grown corn. Fifty-five fall farrowed pigs will be used to follow steers in the winter feed lots.

Lamb Feeding:

The 1675 lambs purchased in the fall of 1921 were fed on the station until March 28. During this time they pastured off 70 acres of the fourth crop of alfalfa and consumed 161 tons of hay and 68 tons of corn silage. Seven hundred lambs were divided into fourteen lots and fed for 60 days to make the following comparisons of rations

for fattening lambs: First, second and third cutting of alfalfa hay; sweet clover hay with alfalfa hay; liberal vs. limited grain rations; the value of silage in rations; beet molasses compared with corn; and the value of cottonseed meal in rations for lambs. The results secured from this trial have been presented in Bulletin 170 and are further summarized in the discussions of the work of the Division of Animal Husbandry in this report.

Eight hundred and seventy-five lambs were purchased in October, 1922, and will be fed at the station during the winter. Fourteen lots of fifty lambs each will again be fed, following much the same plan as the previous year with additional attention to the value of silages and molasses.

Steer Feeding:

Two hundred steers will be fed at the station this winter. They are owned by F. M. Rothrock of Sprague and B. E. McGregor of Prosser and are being fed on margin. They will be fed in nine lots. Four specific studies will be involved, namely: The value of silage and silage plus corn in addition to alfalfa hay in fattening two-year-old steers; the quantity of corn to be fed with hay and silage to fatten yearlings profitably; the value of silage in a hay and grain ration for fattening calves, and the economy of fattening steers as calves, as yearlings and as two-year-olds. The lots when fattened will be yearlings, two-year-olds and three-year-olds.

Irrigation Investigations:

Irrigation investigations were begun this season in co-operation with the Office of Western Irrigation Agriculture of the U. S. Department of Agriculture. The following summary was prepared by Mr. C. C. Wright, the Irrigation Engineer assigned by the office mentioned to this station to carry on the irrigation studies.

In preparation for these investigations, four combination weir and division boxes were installed. These were equipped with Cippoletti weirs and automatic water registering gauges. Continuous records were kept of the amount of water passing over each during the season and the weekly fluctuations of the water delivered to the farm and the total for the season computed. The number of acre feet per acre delivered under each delivery was respectively 3.29, 2.34, 3.07, or an average of 3.13.

With the view of arranging deliveries so that experimental plots could be laid out and served with the least waste of water and inconvenience to other fields, about 3000 feet of eight and ten inch flume to replace earth ditches and small worn out flumes, nine hundred feet of six inch "thin shell" wood stave pipe and six hundred feet of six, eight and fifteen inch concrete pipe were installed.

Six and four-tenths acres with a slope varying from 0.2 to 4.0 feet

in 100 feet and a soil of light sandy loam and weighing approximately 81.9 pounds per cubic feet were prepared for irrigation by the border method. Twenty borders ranging from 200 to 450 feet in length and 30 to 40 feet in width were laid out. The 40 foot borders were prepared on the most level ground and the narrow borders on the steeper parts. Considerable difficulty was experienced in flooding the borders before a crop was established because the soil is so light that it washes very easily. The maximum head of water available was 1.8 cubic feet per second. After two trial irrigations the field was sown to alfalfa and rye, ditched with a "Mormon" ditcher and irrigated with furrows. The present plan is to irrigate the borders by the furrow method until the crop is well set. With some additional work at that time it is thought that the borders can be flooded successfully.

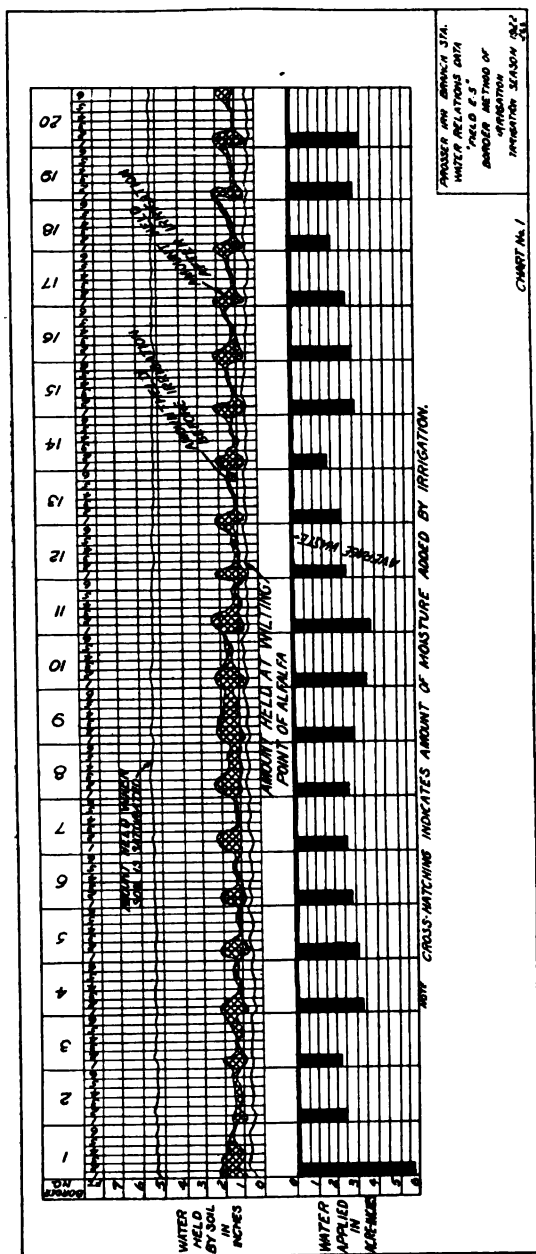
The irrigation water with which the farm is served was sampled, analyzed for salt content and found to be of excellent quality for irrigation water. Twelve samples of underground water were gathered from representative parts of the Yakima Valley and analyzed for comparison.

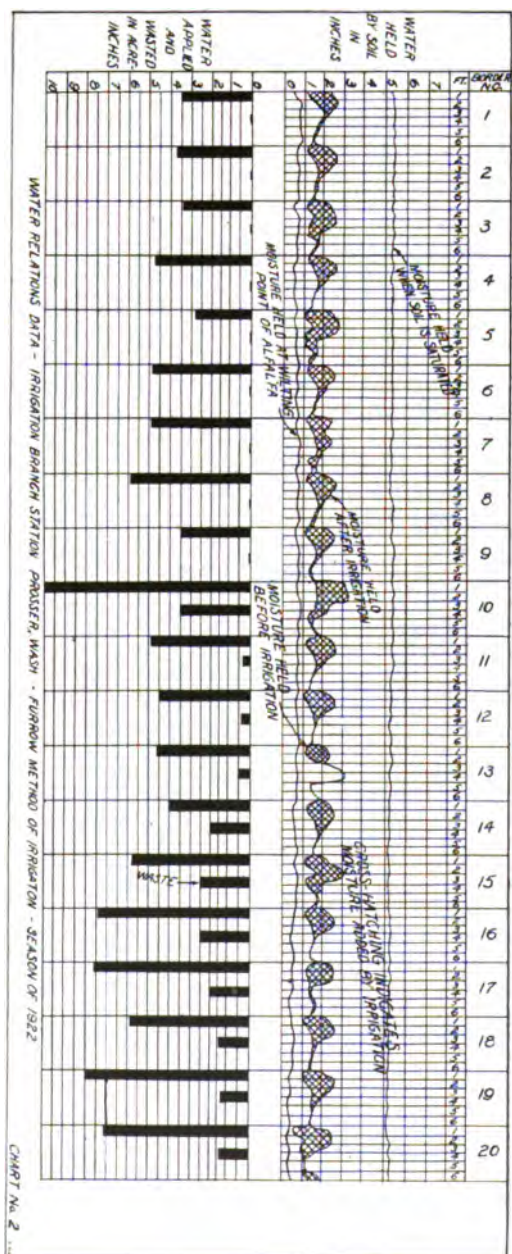
Soil moisture studies were conducted principally in connection with the border experiment. Soil samples were taken with a soil tube immediately before and 48 hours after irrigation. The soil was weighed as it came from the field, dried in a soil oven at a temperature of 100 to 105 degrees centigrade and re-weighed. The difference in weight represented the weight of the soil moisture. This was first converted into percentages of the soil's own weight, then into inches of water by the use of a table prepared from the formula:

$$\left. \begin{array}{l} \text{Percent} \\ \text{Moisture} \\ \text{in} \\ \text{Soil} \end{array} \right\} \times \frac{\text{weight of 1 cu. ft. dry soil}}{100} = \frac{\text{weight of 1 cu. ft. water}}{12}$$

The wilting of alfalfa as indicated in charts (pp. 56-57) is the only average result of two sets of samples but it probably approximates the wilting point very closely. The amount of water held when the water was saturated was determined in the laboratory.

Soil samples were also taken before and after irrigation on several other parts of the farm during the season and it was found that, generally speaking, most of the moisture was held in the first four feet. Only under exceptionally heavy irrigation, a forty-eight hour run for instance, did the samples show any pronounced increase in the fifth and sixth foot. The following table gives the average of 670 soil samples in amount of moisture held before and forty-eight hours after irrigation.





Soil Moisture Percentages Before and After Irrigation

	1st foot	2nd foot	3rd foot	4th foot	5th foot	6th foot
After Irrigation..	14.2	13.1	9.2	11.2	9.6	9.9
Before Irrigation..	5.1	8.1	5.9	8.8	9.5	9.9

Above Percentages Converted Into Inches of Water

After Irrigation....	2.4	2.07	1.45	1.77	1.51	1.56
Before Irrigation..	.80	1.20	0.93	1.39	1.50	1.56
Difference	1.44	0.79	0.52	0.38	0.01	0.00

The results here indicated were obtained by totaling the weights of all the moist samples and doing the same with all the dry samples for each foot of depth, and taking their difference. In other words, the moisture percentages were computed as if all the small samples were combined into large ones for each foot depth, one taken before and one after irrigation.

A percolation test was run on one field to ascertain the rate of lateral distribution of moisture and the rate of its downward movement. Two things were indicated, first that the lateral movement of the water is very uniform, and second, that under the conditions of the experiment a 24 hour run is sufficient for the irrigation moisture to meet the old moisture in a downward direction and also to meet the moisture in a furrow 36 inches away.

A series of soil samples were taken on one of the borders to find the length of time required after irrigation for the soil moisture to come into equilibrium. Water was allowed to run on the border for 48 hours in furrows before sampling was started and then samples were taken at intervals of six hours up to and including the 48 hour period. The results are indicated in the following table.

Soil Moisture Percentages After Irrigation

(Water "on" 48 hours. Furrow method.)

Samples taken immediately after irrigation.

Depth feet	Per cent moisture
1.....	23.7
2.....	24.9
3.....	24.5
4.....	22.1
5.....	10.7
6.....	10.9

Samples taken 12 hours after irrigation.

Depth feet	Per cent moisture
1.....	18.8
2.....	27.3
3.....	26.0
4.....	19.5
5.....	21.0
6.....	21.9

Samples taken 18 hours after irrigation.

Depth feet	Per cent moisture
1.....	20.2
2.....	25.5
3.....	24.5
4.....	19.7
5.....	21.8
6.....	20.1

Samples taken 24 hours after irrigation.

Depth feet	Per cent moisture
1.....	18.5
2.....	25.5
3.....	26.7
4.....	16.3
5.....	22.0
6.....	21.5

**Samples taken 30 hours
after irrigation.**

Depth feet	Per cent moisture
1.....	16.6
2.....	19.5
3.....	24.3
4.....	24
5.....	22.5
6.....	23.1

**Samples taken 36 hours
after irrigation.**

Depth feet	Per cent moisture
1.....	15.8
2.....	22.0
3.....	23.5
4.....	19.0
5.....	18.5
6.....	21.7

**Samples taken 42 hours
after irrigation.**

Depth feet	Per cent moisture
1.....	15.4
2.....	19.6
3.....	14.1
4.....	19.2
5.....	24.7
6.....	18.2

**Samples taken 48 hours
after irrigation.**

Depth feet	Per cent moisture
1.....	15.1
2.....	21.0
3.....	20.7
4.....	19.8
5.....	17.6
6.....	22.0

NOTE: Moisture content before irrigation

Depth feet	Per cent moisture
1.....	14.5
2.....	16.5
3.....	15.7
4.....	9.5
5.....	8.1
6.....	9.4

In the irrigation studies conducted at this station it is proposed:

1. To determine and compare the quantity of water used under different irrigation methods, chiefly the border and furrow methods.
2. To determine the correct soil moisture condition for maximum plant growth.
3. To experiment with methods and rates of application that will maintain this soil moisture condition.
4. To measure water and make soil moisture determinations in the irrigation of different crops under common irrigation practice.
5. To measure all water applied to experimental crops.

THE WATERVILLE BRANCH STATION

C. E. Hill in Charge.

All experimental work on the Waterville Branch Station has been conducted under dry land conditions. The normal annual precipitation for the past 30 years is 12.7 inches. The precipitation for the crop year ending August 31, 1922, was 7.49 inches, which is the lowest on record for this station.

Varietal Trials:

Varietal trials with cereals for hay and grain production have been conducted since 1919. Each year winter wheat has been the most profitable crop and has outyielded spring wheat from 5 to 15 bushels per acre. Previous to 1919 very little winter wheat had been grown in the best section of Douglas County, lying west and north of Waterville, and even now there are many fields which have never been sown in the fall. However, the results obtained with winter wheat have been so outstanding that the acreage has increased each year.

So far, the varietal work has not shown any new varieties of winter wheat that can be recommended in place of Turkey for grain production and Jones Fife for hay. But this work has saved the farmers the expense of importing and experimenting with a number of new varieties not adapted to this section such as Kanred and Burbank's Wonder, which have been widely advertised in daily and farm papers as being superior wheats for the dry sections. The two varieties named are being tested on the station and have yielded less than local Turkey and Fife varieties.

Tillage Experiments:

In changing the cropping of this area from spring wheat to winter wheat there has been a demand for information on the best methods of growing the new crop. For this reason, there has been a greater interest taken in the tillage experiments than in any other line of work conducted on the station. Farmers have observed that the methods of tillage which have been employed in this section for growing spring wheat have not given the best results with winter wheat.

The tillage work on the station includes all methods in vogue in the dry sections of the Northwest. The most outstanding results in 1922 were obtained from tests comparing early and late preparation of the summer fallow. The results are indicated in the following table:

*Tillage	Yield	
	Grain Bu.	Hay Lbs.
Disked April 15—plowed May 10.....	35.9	5510
Not disked	30.1	4280
Disked April 15—plowed June 20.....	33.4	5150
Not disked	20.8	2790
Disked April 15—not plowed.....	36.4	5400

These results show the value of early tillage in the spring. As a large acreage in the Big Bend area is plowed each year in June

*All plats were given clean tillage after plowing until time of seeding in the fall. The plats disked but not plowed were also given clean tillage, using a spring tooth harrow and a rod weeder.

without being disked to kill early growth of volunteer wheat and weeds which rob the soil of moisture and available plant food, these experiments also indicate the possibilities of increasing production on farms in this section.

Other results from the tillage experiments in 1922 are shown in the following table:

Depth of Plowing and Packing After Plowing, in Connection With Time of Plowing and Tillage Before Plowing for Winter Wheat Production.

Table A—YIELD OF SEED

Depth of Plowing	Disked April 15 Plowed June 20			Not Disked Plowed June 20			Not Disked Plowed May 10		
	Not			Not			Not		
	Pckd.	Pckd.	Ave.	Pckd.	Pckd.	Ave.	Pckd.	Pckd.	Ave.
	Bu. per acre			Bu. per acre			Bu. per acre		
Deep 11"	33.7	31.7	32.7	19.3	19.3	19.3	29.0	28.3	28.6
Medium 7"	32.0	33.7	32.8	22.0	19.0	20.5	31.0	30.0	30.5
Shallow 4"	33.7	35.7	34.7	23.7	21.3	22.5	32.3	30.0	21.1
Average	33.1	33.7	33.4	21.7	19.9	20.8	30.8	29.4	30.1

Table B—YIELD OF HAY

Depth of Plowing	Disked April 15 Plowed June 20			Not Disked Plowed June 20			Not Disked Plowed May 10		
	Not			Not			Not		
	Pckd.	Pckd.	Ave.	Pckd.	Pckd.	Ave.	Pckd.	Pckd.	Ave.
	Lbs. per acre			Lbs. per acre			Lbs. per acre		
Deep 11"	5320	4760	5040	2620	2700	2660	4160	4120	4140
Medium 7"	4840	5380	5110	2800	2660	2730	4300	4180	4240
Shallow 4"	4960	5660	5310	3020	2960	2990	4480	4440	4460
Average	5040	5267	5153	2813	2773	2793	4313	4247	4280

Harrowing Winter Wheat in the Spring:

Experiments to determine the value of the practice of harrowing winter wheat in the spring have been conducted since 1919. In no year have the yields been increased by harrowing. The lower yields are caused by many of the plants being killed in harrowing, covering the wheat with clods, retarding the growth and weakening the plants so that wireworms do greater damage. The average yields for four years from harrowing at different times each year are as follows: Not harrowing, 27.1 bushels per acre; harrowed early spring, 23.3 bushels; harrowed medium early spring, 24.7 bushels, and harrowed late spring, 26.4 bushels. The earliest harrowing was done each year as soon as the ground was dry enough to be worked and before a crust had formed. The greatest damage was done by harrowing at this time. The later harrowing tests were done at intervals of from two to three weeks.

Seed Treatment:

The new method of treating wheat with dry copper carbonate has given satisfactory results in the control of smut, without causing any apparent injury to the germination of the seed. While the new method is an improvement over the bluestone and formaldehyde treatments, which often cause poor germination, it is the aim of this station to find smut proof varieties which can be sown without treatment and which will equal the present varieties in yield and quality. Five smut proof varieties, two obtained from the main Experiment Station at Pullman and three from the Dry Land Station at Moro, Oregon, were sown on the Waterville Station in the fall of 1922. Excellent stands were obtained and the results will be watched with interest in 1923.

Rotation Experiments:

Preliminary rotation experiments, including forage and cereal crops, have been conducted each year with a view of working out a permanent series. Ground was prepared in 1922 and it is planned to start the permanent work in 1923.

Inspection of the Station by Farmers:

The number of farmers who visited the Station in 1922 was more than double that of any previous year. The Annual Field Day held in July in co-operation with the Waterville Chamber of Commerce and the County Agent, was probably the largest gathering of the kind in the history of Douglas County. The Chamber of Commerce served a free lunch at noon to over 500 farmers.

PUBLICATIONS

The following bulletins were prepared by members of the Experiment Station staff and published during the year. In addition, a considerable number of papers were prepared and published in technical journals.

General Bulletins

- 166 The Silt Loam Soils of Eastern Washington and Their Management, by F. J. Sievers and H. F. Holtz.
- 167 Thirty-first Annual Report.
- 168 The Dusting of Wheat for Bunt or Stinking Smut, by F. D. Heald and L. J. Smith.
- 169 Hog Feeding Experiments, by H. Hackedorn and J. Sotola.
- 170 Lamb Feeding Experiments at the Irrigation Branch Station, by H. Hackedorn, R. P. Bean and J. Sotola.

FINANCIAL STATEMENT
WASHINGTON AGRICULTURAL EXPERIMENT STATION
 in account with
THE UNITED STATES APPROPRIATIONS, 1921-1922

Dr.	Hatch	Adams
Receipts from the Treasurer of the United States, as per appropriations for fiscal year ended June 30, 1922, under acts of Congress approved March 2, 1887 (Hatch Fund), and March 16, 1906 (Adams Fund).....	\$15,000.00	\$15,000.00
Cr.	Abstract	
By Salaries	1 8,536.51	12,783.28
Labor	2 2,371.78	1,154.55
Publications	3 2,139.91	
Postage and stationery	4 44.11	12.62
Freight and express	5	5.00
Heat, light, water and power.....	6 71.82	
Chemicals and laboratory supplies.....	7 53.04	124.22
Seeds, plants and sundry supplies.....	8 189.30	22.38
Fertilizers	9 51.69	
Feeding stuffs	10	
Library	11	
Tools, machinery and appliances.....	12 22.14	122.41
Furniture and fixtures	13 75.85	3.67
Scientific apparatus and specimens.....	14 335.25	516.57
Live stock	15	66.00
Traveling expenses	16 1,108.60	189.30
Contingent expenses	17	
Buildings and land.....	18	
Balance		
Total	\$15,000.00	\$15,000.00

FINANCIAL STATEMENT

State Funds Expended on the Main Station and All Branch Stations
 (Excepting the Western Washington Station, which is operated
 independently)

April 1, 1921, to March 31, 1922

Dr.	State Appropriations	Sales	Total
To balance on hand		\$ 597.14	\$ 597.14
Receipts from other sources than the			
U. S. for the year ended.....	\$55,385.61	29,671.92	85,057.53
Total	\$55,385.61	\$30,269.06	\$85,654.67
Cr.			
Salaries	\$23,267.25	\$ 928.34	\$24,195.59
Labor	13,093.98	6,444.69	19,538.67
Publications	82.62	965.73	1,048.35
Postage, stationery, telephone and telegraph	934.90	248.59	1,183.49

FINANCIAL STATEMENT—Continued

	Cr.	State Appropriations	Sales	Total
Freight and express		607.48	290.46	897.94
Heat, light and water		573.53	10.50	584.03
Chemical supplies		503.68	205.00	708.68
Seeds, plants and sundries		5,263.38	614.57	5,877.95
Fertilizers		96.95	16.20	113.15
Feeding stuffs		359.42	2,764.14	3,123.56
Library		409.21	113.10	522.31
Tools, machinery, appliances		2,788.90	185.15	2,974.05
Furniture and fixtures		309.45	104.72	414.17
Scientific apparatus		243.99	10.21	254.20
Live stock		697.00	8,009.32	8,706.32
Traveling expenses		3,541.85	488.46	4,030.31
Buildings and lands		2,612.02	606.59	3,218.61
Balance			8,263.29	8,263.29
Total		\$55,385.61	\$30,269.06	\$85,654.67

FINANCIAL STATEMENT

Western Washington Station

April 1, 1921, to March 31, 1922

	Dr.	State Appropriations	Sales	Total
To Balance on hand			\$ 902.78	\$ 902.78
Receipts		\$49,289.17	19,926.67	69,215.84
Total		\$49,289.17	\$20,829.45	\$70,118.62
	Cr.			
Salaries		\$19,373.05	\$ 4,311.60	\$23,684.65
Labor		12,437.34	3,169.77	15,607.11
Publications		1,064.19	3,626.63	4,690.82
Postage, telephone and telegraph		750.74	1,367.08	2,117.82
Freight and express		241.53	26.95	268.48
Heat, light and water		1,083.46	145.69	1,229.15
Seeds, plants and sundries		3,135.13		3,135.13
Fertilizers		120.97		120.97
Feeding stuffs		7,877.11	2,078.31	9,955.42
Library		10.00	95.28	105.28
Tools, machinery, appliances		315.38	205.99	521.37
Furniture and fixtures		108.60	256.20	364.80
Live stock		30.00	717.68	747.68
Traveling expenses		1,006.51	532.13	1,538.64
Buildings and lands		1,735.16	1,483.13	3,218.29
Balance			2,813.01	2,813.01
Total		\$49,289.17	\$20,829.45	\$70,118.62

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